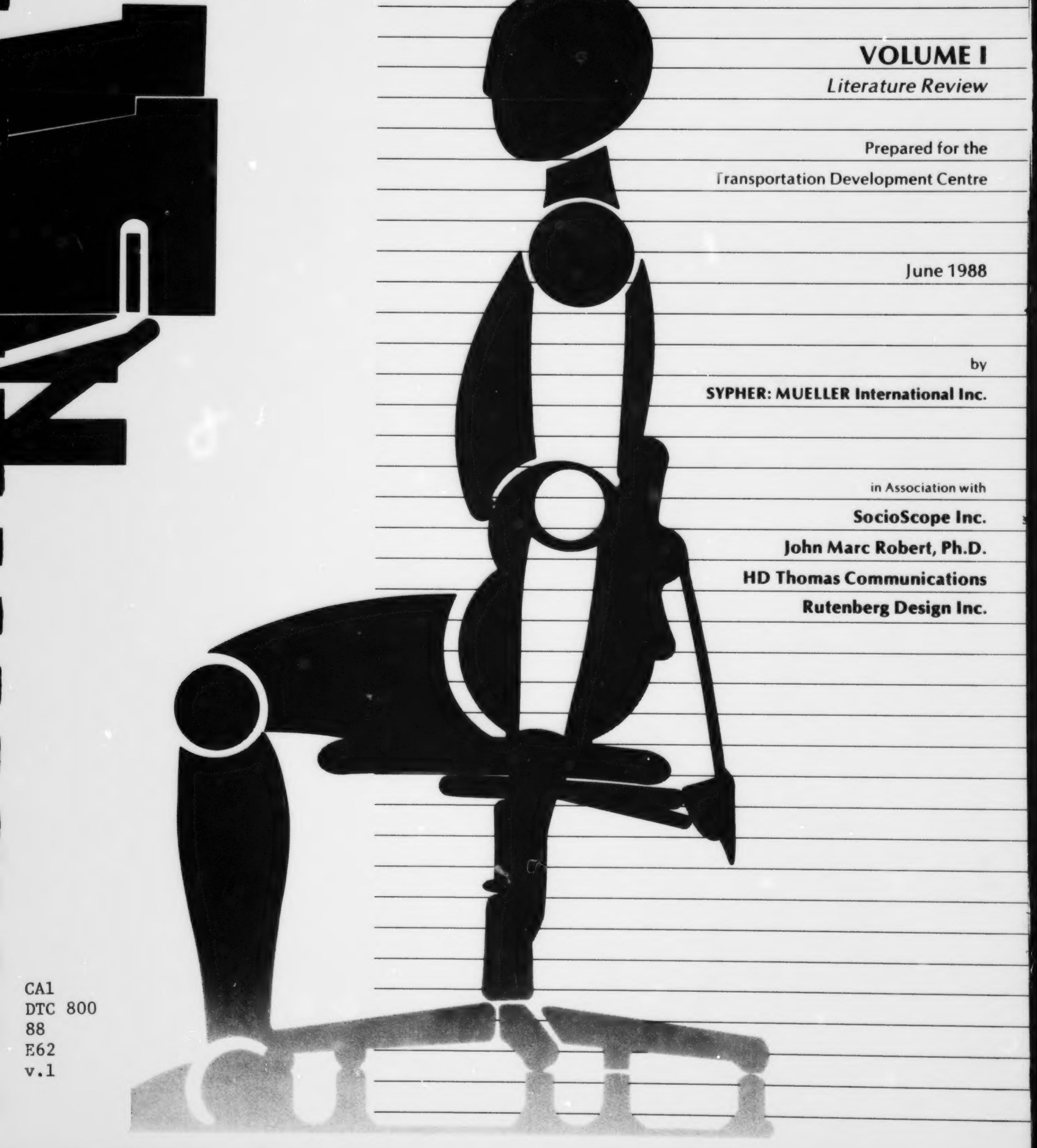
TP8742E

Ergonomically Designed Workstation
for Training of Electronic Systems Maintenance Technicians



VOLUME I

Literature Review

Prepared for the
Transportation Development Centre

June 1988

by

SYPHER: MUELLER International Inc.

in Association with

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John Marc Robert, Ph.D.
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17 Abstract

Volume I of this study is a comprehensive literature review summarizing the current state of knowledge and practice with respect to the ergonomic design and use of workstations and the ergonomy of computer aided learning. The literature review consists of three parts: a review of the ergonomy of computer workstations; a review of currently accepted ergonomics standards and norms with respect to workstation design and use; and a review of the ergonomy of computer aided learning.

Volume II contains four task reports. They are: Report on Baseline Analysis of Typical Training Tasks to be Performed at Training Workstation; Input Devices for Interactive Computer Systems; Design Recommendations; and Development of a Training Workstation.

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17. Resume

Le tome I du rapport donne le résultat de la recherche documentaire faisant le point sur les connaissances et pratiques en matière d'étude et exploitation ergonomiques des postes de travail ainsi que sur l'ergonomie appliquée à l'enseignement assisté par ordinateur, EAO. Cette recherche se divise en trois parties: tour d'horizon des applications de l'ergonomie aux postes de travail en informatique; tour d'horizon des normes et lignes directrices utilisées en ergonomie, et applicables à l'étude et l'usage des postes de travail; revue des applications de l'ergonomie à l'enseignement assisté par ordinateur.

Le tome II renferme les quatre rapports suivants: Analyse de base des tâches d'enseignement types à être exécutées sur un poste de travail; Dispositifs d'interaction avec un ordinateur; Critères de conception; Mise au point d'un poste de travail en EAO.

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PREFACE

This report (Volume I), represents a comprehensive literature review on the ergonomics of computer aided learning and workstation design. The synthesis of a series of task reports for the project "To Identify The Requirements For An Ergonomically Suitable Single-User Student Learning Centre For Electronic Systems Maintenance Technicians"is presented as a separate report (Volume II).

SUMMARY

In September of 1985, in order to foster the application of the most advanced knowledge in the area of ergonomics to the design of training and training technologies, the Transportation Development Centre of Transport Canada initiated a two-year project for the development of an ergonomically designed workstation for the training of electronic systems maintenance technicians.

The specific objective of the project was to develop a prototype of a workstation which incorporated the current state-of-the-art in ergonomic knowledge in such areas as workstation design and computer aided learning. (Workstation is the term used to describe a self-contained working environment, usually one where an individual is working with a computer terminal.)

The project began with an extensive review of the literature pertaining to the ergonomics of computer aided learning and of workstation design and a review of currently accepted ergonomic standards and norms with respect to workstation design and use. Recommendations with respect to the ergonomic requirements for the workstation design were developed as for example in the areas of lighting, air quality, heating, sound isolation, design and placement of the hardware and so on.

A review of the likely users of the system and the environments in which these systems might be placed determined that the system should be designed so as to be appropriate for a broad range of office environments constructed over the last 40 years and where extensive renovations may not have been undertaken.

The user population will be some 1200 technicians across Canada, primarily male, both French and English speaking, "in good physical condition" and of average height and weight. Also taken into consideration were users dependent on wheelchairs for mobility.

The issue of "embedded training" and the number and type of monitors required was examined and it was concluded that there would be a requirement for a training device over and above any training which might be available in "embedded" form in any of the new technologies being acquired. It was also concluded that for the foreseeable future, two screens would be required to accommodate the needs of the training system.

An examination was conducted to determine whether computer aided learning would satisfy the training requirements for the target user group. It was decided that attention would be concentrated on only a subset of anticipated technician training requirements (the RAMP system), because the new technical systems for which the technicians were being trained were not, for the most part, fully developed as yet.

A detailed task analysis of the RAMP system was conducted; the identified tasks were used as a basis for determining which would be the most effective teaching media for delivering the required training. It was concluded that computer aided learning is definitely able to provide instruction on most, if not all of the 373 RAMP training objectives.

A human factors review of most common input devices (keyboards, touchscreens, lightpens, mice, trackballs, joysticks, graphics tablets, and speech recognition) used for interacting with computers was undertaken. Their principal advantages and disadvantages and practical guidelines and criteria for selecting the best input device for a given application were documented. It was concluded that the different devices had a variety of advantages and disadvantages in such areas as ease of use, applicability to particular kinds of applications, and prerequisite knowledge and that no definitive selection could be made in advance of a detailed knowledge of the particular training modules which would be undertaken.

It was difficult to make definitive recommendations in some areas concerning the design and implementation of the workstation without knowing in more detail the nature of the software which will be used. However, certain recommendations can be made irrespective of the specific content of the courseware to be developed:

- the microprocessor should be sufficiently powerful to support the computer aided learning software and sufficiently reliable and robust for a range of office environments;

- the input/output devices should be the most advanced, proven devices and selected so as to facilitate computer use by inexperienced computer users;

- the workstation should be able to accommodate two persons working side-by-side;

- there should be sufficient space for the possible placement of one or two displays, one or two keyboards, a pointing device (such as a mouse), a modem, a printer, a microphone, paper, headphones, a telephone, a calculator, writing pads, pencils, rulers, a document holder, and a desk lamp;

- sufficient storage space should be provided for reference manuals, documents, printouts;

- the operator should be able to easily reach and operate the controls of the various devices listed above;

- the desk height should be adjustable and allow for wheelchair access;

- the chair should have a five-point base, with adjustable seat height and back rest, and castors;

- terminals should be oriented such that the operator and the screen are not facing the window;

- stable air conditions should be maintained during working hours (between 21°C and 28°C) and thermal emissions for the VDTs should be taken into account when calculating the air conditioning requirements of the room;

- special precautions should be taken to safeguard against the discharge of static electricity to the VDT chassis.

Three design options were developed incorporating the design recommendations. These were evaluated against the criteria developed with respect to ergonomic and design requirements and as a result a fourth option was identified with incorporated certain features of the three earlier options. A design sketch of the mock-up may be seen in Figure 1 below.

The workstation prototype -- CAL-STATION -- allows for a clearly defined area, providing semi-privacy without creating a feeling of confinment in an enclosed space. Any distractions in the environment such as bright lights, glare and background noise are controllable.

The CAL-STATION consists of a U-shaped wall system which supports the basic components of the workstation. The ceiling structure, work surface and monitors are all components firmly secured to the structural frames of the walls, but can be easily detached for replacement and maintenance.

The walls house all electrical wiring which can be accessed for servicing by removing the exterior panels.

The easy assembly of the system allows for rapid installation. CAL-STATION is to be identified as a learning place, not to impose, but to blend into an existing office environment.

The overall appearance is that of an open, light structure. The walls offer visual privacy to the user and create an acoustic barrier from the surrounding environment.

The form of the workstation is tapered to visually reduce its overall mass and to permit placing two or more units next to one another, forming a multiple workstation and thereby minimizing floor space.

The interior and exterior of the workstation are beige, which blends well various office environments and does not disturb the user while working at the station.

The work surface is mauve with low reflectance. All controls an handles are magenta, a bright colour visibly defining elements that can be adjusted by the user and indicating proper and safe positioning of hands for moving the components.

The overall size of CAL-STATION was based on the space required for a technican to comfortably perform all task and necessary movements of monitors without being wider than standard office desks. It also fits into areas with low ceilings (of approximately 2.7 m).

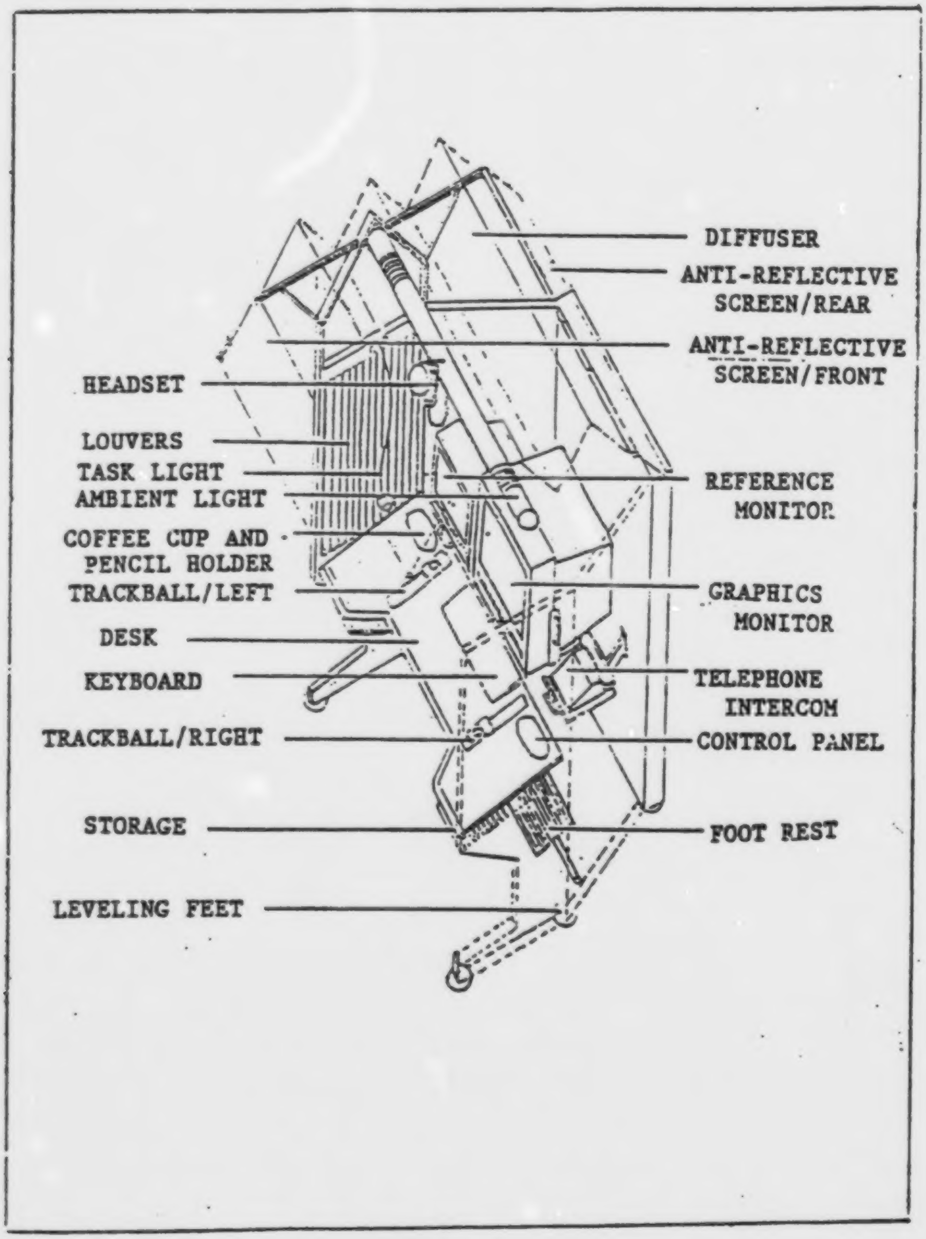

Figure 1. CAL STATION

SOMMAIRE

En septembre 1985, afin d'encourager l'application des techniques ergonomiques les plus récentes au domaine de l'enseignement et aux technologies connexes, le Centre de développement des transports de Transports Canada a lancé un projet d'étude et de développement d'un poste de travail ergonomique destiné à la formation des électroniciens aéronautiques.

Ce projet d'une durée de deux ans a eu pour objectif la réalisation d'un prototype de poste, incorporant toutes les connaissances accumulées en ergonomie et appliquées tant à l'étude d'un poste de travail qu'aux méthodes d'enseignement assisté par ordinateur, EAO, à y être utilisées. Le terme poste de travail désigne un endroit généralement autonome où sont concentrés les outils ou les aides informatiques aptes à l'exécution d'une tâche.

Le contractant a commencé par une recherche documentaire exhaustive sur les applications de l'ergonomie tant à l'EAO qu'à l'étude et l'usage d'un poste de travail, complétée par un tour d'horizon des normes et des lignes directrices utilisées en ergonomie et applicables aux domaines concernés. Cette recherche a débouché sur des recommandations relatives à certaines caractéristiques du poste envisagé, notamment en matière d'éclairage, ventilation, chauffage, isolement acoustique et touchant également le dimensionnement et la disposition des outils et des aides.

La prise en compte des utilisateurs éventuels du poste ainsi que des milieux dans lesquels il pourra être implanté, a montré que le poste en question devrait être adaptable à la plupart des bureaux construits durant les 40 dernières années et qui n'ont peut-être pas tous été rénovés en profondeur depuis.

La population cible des utilisateurs s'élève à quelque 1 200 techniciens canadiens, en majorité de sexe masculin, de langue francaise et anglaise, en bonne condition physique et dont la taille et le poids se situent dans la moyenne. Il a également été prévu qu'un certain nombre d'entre eux serait en fauteuil roulant.

La question de la "formation intégrée" et celle du nombre et du type d'écrans de visualisation à prévoir ont été abordées. L'examen de ces questions a montré qu'il serait nécessaire de disposer d'un outil supplémentaire permettant de parachever la formation initiale à l'exploitation des nouvelles technologies qu'il est envisagé d'acquérir, et qu'il serait préférable de pouvoir disposer au début de deux écrans de visualisation, du moins pour les besoins prévus dans le proche avenir.

Une autre question abordée a été celle de déterminer si la méthode d'enseignement assisté par ordinateur pourrait répondre aux besoins de formation des utilisateurs visés. La décision prise à cet égard a été qu'il serait préférable de se cantonner pour le moment à un volet de ces besoins, soit celui qui a trait au système RAMP, étant donné que les nouveaux systèmes sur lesquels les techniciens seront appelés à travailler à l'avenir ne sont pas, dans la plupart des cas, encore tout à fait au point.

Une analyse fouillée des tâches reliées au système RAMP a été faite; ces tâches ont servi à déterminer la méthode d'enseignement la plus appropriée. La recherche a montré que l'EAO est effectivement la méthode qui permettra aux responsables de satisfaire la plupart des 373 objectifs de formation rattachés au système RAMP.

L'étape suivante a été d'examiner sous l'angle de l'ergonomie les dispositifs d'entrée les plus répandus: clavier, écran tactile, crayon optique, souris, boule, manche à balai, tablette graphique et commande vocale pour communiquer avec l'ordinateur. La recherche a débouché sur une documentation touchant les principaux avantages et inconvénients de chacun de ces dispositifs et sur l'élaboration de lignes directrices et de critères pour la sélection de celui qui serait le mieux adapté à l'utilisation envisagée. Chaque dispositif possède des avantages et présente des inconvénients qui lui sont propres. Les caractéristiques comme la convivialité, la plus ou moins grande aptitude aux diverses utilisations et l'apprentissage préalable nécessaire peuvent varier de sorte qu'aucun choix ne saurait être fait de façon certaine sans une connaissance approfondie de l'application envisagée.

De même, il a été difficile de formuler des recommandations définitives sur certains aspects du poste de travail alors que le type de logiciel devant y être utilisé restait encore inconnu. Néanmoins, les recommandations suivantes ont pu être faites :

- le micro-ordinateur devrait être d'une puissance adéquate pour piloter le cours d'enseignement assisté par ordinateur, et avoir la fiabilité et la robustesse nécessaires pour résister à tous les milieux d'implantation prévisibles;

- les dispositifs d'entrée et de sortie doivent être les plus modernes et les plus fiables, et choisis pour la plus grande convivialité possible;

- le poste doit pouvoir accueillir deux personnes travaillant côte à côte;

- le poste doit pouvoir recevoir une ou peut-être deux unités de visualisation, un ou deux claviers, un dispositif d'interaction (une souris, par exemple), un modem, une imprimante, un microphone, des écouteurs, un téléphone, une calculatrice, des blocs-notes, crayons, papier, et règles, une corbeille et une lampe;

- il faut aussi de l'espace pour les manuels, la documentation, les imprimés;

- l'opérateur doit pouvoir saisir et actionner les commandes des dispositifs cités en toute facilité;

- le pupitre doit être réglable en hauteur et permettre l'accès d'une personne en fauteuil roulant;

- le siège doit s'appuyer sur le sol par cinq points d'appui munis de roulettes, il doit être réglable en hauteur et avoir un dossier également réglable;

- ni l'opérateur ni les écrans de visualisation ne doivent se trouver face aux fenêtres;

- des conditions ambiantes stables êntre 21 et 28°C doivent être maintenues durant les heures de travail. L'apport thermique des unités de visualisation doit être pris en compte dans le calcul des installations de climatisation;

- une protection spéciale doit être prévue contre le risque de décharge d'électricité statique vers le bâti des unités de visualisation.

Toutes ces recommandations ont été reprises dans trois architectures, dont l'évaluation en fonction des critères de conception et d'ergonomie retenus a débouché sur une quatrième où certaines caractéristiques des trois précédentes ont été reprises. La maquette de celle-ci est esquissée à la figure 1.

Ce prototype de poste, désigné CAL-STATION, découpe une aire de travail nettement définie, offrant un demi-isolement dont l'avantage est d'éviter un sentiment d'étouffement. Toutes les nuisances extérieures, comme les luminances trop fortes, l'éblouissement et le bruit de fond, y parviennent atténuées.

Une architecture à parois en U constitue le support sur lequel sont accrochés le plafond, le plan de travail et les unités de visualisation, et duquel ceux-ci peuvent être aisément décrochés pour les besoins de l'entretien et de la maintenance.

Dans les parois habillant l'architecture sont logés les fils électriques dont l'accès est possible par l'enlèvement d'un panneau.

D'assemblage facile et rapide, ce poste doit pouvoir être reconnu pour ce qu'il est: un lieu destiné à l'apprentissage; il doit donc s'harmoniser avec le milieu où il se trouve.

Tout en offrant une apparence ouverte et légère, le poste, grâce aux parois qui l'habillent, soustrait l'occupant aux regards et le protège du bruit environnant.

Des parois obliques enlèvent toute impression de lourdeur et permettent, en outre, d'installer plusieurs postes côte à côte et former ainsi une grappe multiposte, économisant ainsi l'espace de plancher occupé.

Les surfaces extérieure et intérieure du poste sont de couleur beige, qui se marie bien à tous les décors où il peut être implanté. Pour l'utilisateur, c'est une couleur très acceptable.

Le plan de travail est de couleur mauve, assez mate. Par contre, les commandes et leviers sont de couleur magenta, couleur brillante qui permet de définir le contour des éléments devant être manipulés par l'utilisateur, et à celui-ci de voir l'endroit exact où placer ses mains.

Enfin, le poste a été dimensionné en fonction de l'espace dont l'utilisateur a besoin pour exécuter les tâches prévues et pour manipuler les commandes à sa portée, sa largeur n'étant pas plus grande que celle d'un bureau de dimensions standard. Verticalement, sa hauteur lui permet de s'insérer dans des locaux où le plafond n'est qu'à 2,7 m du plancher.

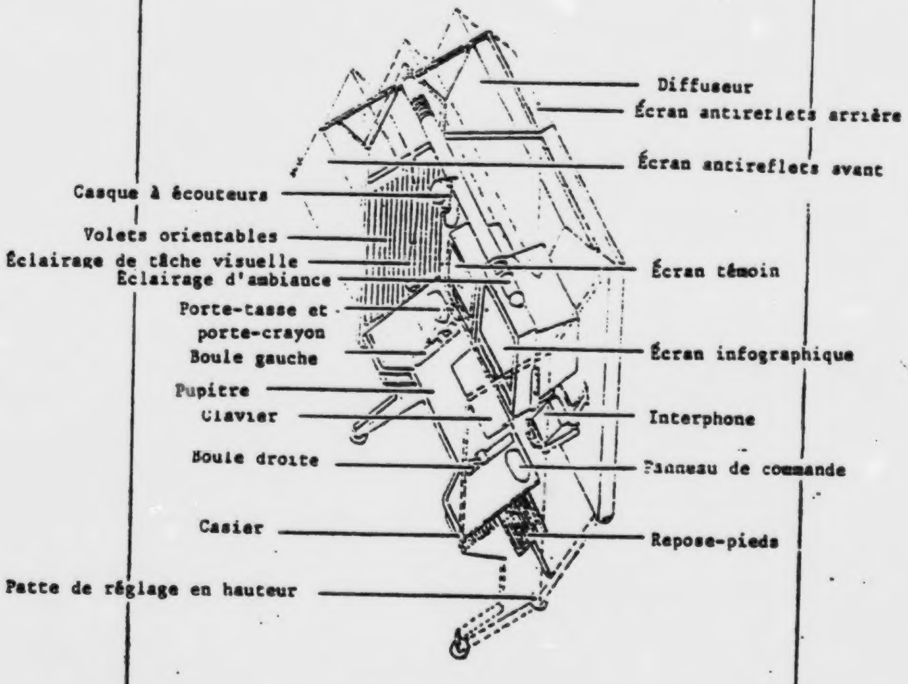

Figure 1. Poste de travail

TABLE OF CONTENTS

1. LITERATURE REVIEW: ERGONOMY OF COMPUTER-AIDED LEARNING 1
1.1 Introduction 1
1.2 Psychological Background to Computer-Aided Learning 3
1.2.1 General 3
1.2.2 Adult Learning 3
1.2.2.1 Cognitive Styles 5
1.2.2.2 Other Factors in Adult Learning Ability 6
1.2.3 Cognitive Theory 6
1.2.3.1 Short-Term Memory 7
1.2.3.2 Long-Term Memory 7
1.2.3.3 Problem Solving 7
1.2.3.4 Empirical Studies 8
1.2.3.5 Directing a Computer's Actions 8
1.2.3.6 Visual Displays 10
1.2.3.7 Interaction with Computers by Voice and Other Modalities 10
1.2.4 Implications 11
1.3 Research Findings in Computer-Aided Learning 14
1.4 CAL and Ergonomic Factors 15
1.4.1 Introduction 15
1.4.2 Advantages and Disadvantages of CAL 15
1.4.3 Issues 16
1.4.3.1 Timing 16
1.4.3.2 Reliability of the System 16
1.4.3.3 Course Content 17
1.4.3.4 Course Structure 17
1.4.4 Media Use 17
1.4.5 Ease of Use 17
1.4.6 Screen Display 18
1.4.7 Interaction 18
1.4.8 Level of Difficulty 19
1.4.9 Control 19
1.4.10 Error Checks 19
1.4.11 Scoring 19
1.4.12 Assessment & Remedial Channelling 20
1.5 Ergonomic Factors of the Interactive Computer Systems 20
1.5.1 Objectives 20
1.5.2 Principles for Designing Friendly Software 20
1.5.3 Ergonomic Criteria for User Friendliness 28
1.5.3.1 Direct Manipulation 28
1.5.3.2 Exploration 29
1.5.3.3 Feedback 30
1.5.3.4 Consistency 31
1.5.3.5 Transparency 32
1.5.3.6 Pleasure 32
1.6 Conclusion 33

Bibliography 35

2. LITERATURE REVIEW: ERGONOMY OF COMPUTER WORKSTATIONS 59
2.1 Introduction 59
2.2 Terminal 60
  2.2.1 Visual Display 60
  2.2.2 Screen Filters 65
  2.2.3 Keyboard 66
2.3 Workstation 70
  2.3.1 Desk 70
  2.3.2 Chair 71
  2.3.3 Documents 73
  2.3.4 Document Holder 73
  2.3.5 Foot Rest 74
  2.3.6 Working Posture 75
2.4 Work Environment 77
  2.4.1 Position of the Terminal 77
  2.4.2 Lighting 78
  2.4.3 Room Climate 81
  2.4.4 Noise 81
  2.4.5 Static Electricity 82
  2.4.6 Other Aspects 82
2.5 Restrictions in Working with VDTs 82
2.6 Other Issues 82

Bibliography 84

3. LITERATURE REVIEW: ERGONOMIC STANDARDS AND NORMS 89
3.1 Introduction 89
3.2 Radiation 90
  3.2.1 Ionized Radiations 91
  3.2.2 Non-Ionized Radiations 91
  3.2.3 Regulations and Guidelines 91
  3.2.3.1 Maintenance of VDTs 91
  3.2.3.2 Anti-radiation Protection 91
  3.2.3.3 Pregnancy 92
3.3 Visual Discomfort 92
  3.3.1 Potential Factors 92
  3.3.1.1 Regulations and Guidelines 93
  3.3.1.2 The Lightning Environment 93
  3.3.1.3 Individual Factors 94
3.4 Musculoskeletal Problems 94
  3.4.1 Standards and Guidelines 95
  3.4.1.1 The Hardware Environment: The Furniture 95
  3.4.2 Pauses and Working Time 95
3.5 Occupational Stress 96
  3.5.1 Work Organization Standards and Guidelines 96

Bibliography 97

ANNEX 1: Regulations and Guidelines of Governmental and Non-Governmental Associations

1. LITERATURE REVIEW: ERGONOMY OF COMPUTER-AIDED LEARNING

1.1 Introduction

In the years since World War II, man has come to be viewed as an active processor of information. More recently, new understandings of human cognitive behavior in the areas of performance, memory, learning, and problem-solving have been developed and framed within an information-processing perspective. The applications for this new knowledge are enormous, particularly within the domain of the human computer interface. The power of computers is being felt throughout the entire fabric of society as we move along the continuum from an industrial society toward an information society, and the success with which this transition is made will depend critically on the quality of human-computer interaction. As technological advances make possible major changes in our workplaces, we are confronted with an enormous educational and training challenge. Our concern in this literature review is to focus on what is known about the human-computer interface that may be applied to the development of computer-assisted learning.

The report is presented in two major sections. The first section (1.2) covers what is currently known about the psychological background to learning as applied to computer-aided learning, including adult learning theory and cognitive theory and their implications for the development of CAL. An extensive bibliography is provided.

The second section (1.3 and 1.4) deals more specifically with research concerning CAL and covers the ergonomy of computer-assisted learning, including a review of research results and of ergonomic issues affecting the utilization of CAL.

The use of computers as an assist to learning (computer-assisted learning - CAL), in both the classroom and the workplace, is now a reality. Technology has made this feasible. Its effectiveness as compared to other pedagogical tools is however still relatively unevaluated. Research results are not as yet conclusive, as Kidd & Holmes point out -

> "due to the lack of similarities [among] experiments in terms of the courseware used, the mode of implementation, the skills developed, the areas of performance tested and the means of testing," which causes results to "remain inextricably wed to the specific set of conditions which produced them." [94, p. 78]

The reason for this as they note is:

> "Statistical evidence is not the only form of evaluation, nor is it necessarily the best or most accurate form." [94, p.78]

In practice, the approach adopted has been that CAL technology exists and thus should be used. It has moreover generally been accepted as a viable tool of instruction on its own or in conjunction with conventional instruction, with its own set of advantages and disadvantages.

One of the most powerful features of CAL is the simulation capabilities it provides. Particularly in the work environment, this feature is of great importance and relevance. Kearsley and Hillelsohn note that it is,

> "well suited for teaching process/procedural concepts and problem-solving strategies." [95, p.78]

The authors further note that the advantage of CAL for simulation are its possibilities for experimentation by the user, without the real world effects of actual experimentation. A problem can be worked and reworked endlessly, at the user's own pace. It is particularly useful in situations in which activities:

> "(a) Take a long time to occur in the real world, but can happen quickly in the computer simulation (e.g., the breakdown of a component in the system);
> (b) require the use of special, unavailable, rare and/or expensive equipment (e.g., going through the test procedures on a weapons system);
> (c) are prone to error-making, therefore requiring frequent feedback (e.g., troubleshooting a complex system);
> (d) are dangerous to perform, especially while in a novice status (e.g., the handling of nuclear materials)." [95, p. 79)

Kearsley and Hillelsohn give the areas in which computers can be used in training as those which:

> "serve as the instructional development, delivery, management, or testing system; provide an information resource or problem-solving tool for students, instructors, or managers; schedule or allocate training resources (equipment, facilities, materials); keep records and generate reports; serve as a communications medium or job aid; and provide student counselling or guidance." [95, p.75)

Horn et al. for their part give it as,

> "initial learning, review or relearning, reference, briefing and browsing, updating skills and information, job-aid." [94, p. 105]

As Ketner [96] in his article notes, Air Force studies have indicated that retention dissipates rapidly in highly technical procedure training. Integrating videodisk with computer is seen as viable means of addressing this problem.

Evidently given the above, the area of air traffic control electronics maintenance is an application for which CAL can be used effectively to assist training.

1.2 The Psychological Background to Computer-Aided Learning

1.2.1 General

Topics addressed in this section include adult learning, cognitive theory, and implications for computer-assisted learning.

1.2.2 Adult Learning

The history of research into adult learning ability can be traced back to the pioneer work of Francis Galton (1822-1911). Research by Thorndike and Lorge conducted in the 1920's and 1930's concluded that adults can learn up to age 70. A great quantity of excellent research on adult learning was produced between the 1930's and 1965. The results of these and other studies are addressed below.

Learning ability is usually discussed in terms of performance. It has also been conceptualized along the dimensions of capacity to learn and the rate of learning. Studies which have focused upon ability to learn over the life-span have generally concluded that performance declines significantly between ages 25 and 50.

Blum and Jarvik [53] (1974) are among the researchers who have concluded that there is a positive association between educational achievement level and intellectual functioning.

An important study of adults eighteen through seventy-five years of age by Knox and Sjogrenn [60] (1965) reported three major findings. In the first set of findings, age was not found to be associated with performance of learning activities. Furthermore, there was no observed difference between older and younger subjects on the Wechsler Adult Intelligence scale. Finally, they also observed a significant positive relationship between achievement and educational level.

Second, these researchers found that half of their subjects had participated in some adult education activity in the previous five years, whereas the other half had not. Although there were no other differences between the two groups, pre-test scores for the group that had previously participated in educational activities were higher than for non-participants. These findings support the opinion that learning ability can decline with disuse.

The third finding discussed by Knox and Sjogren concerns the pace of learning. Learners performed best at their own pace. When required to learn at a pace faster or slower than their preferred pace, achievement declined about equally for all groups. In general, the

the older subjects, those with less formal education, and those who had not recently participated in educational activities, preferred a slower pace. In general those who set a faster pace achieved better.

Knox, Grotelueschen and Sjogren [54] (1968) investigated the association between learning ability and recent participation in a learning activity. They concluded that recent participants learned more effectively for two reasons: (1) the adult who has not recently participated in education may have become less able in the use of study skills, and (2) participants may have achieved a broader background of knowledge and information that enables them to more readily acquire and retain new information.

Monge and Gardner [63] (1972) developed twenty-eight tests designed to discern differential age trends among adults. Some of their findings are noted below.

Younger adults performed better than older adults on tests of an educational nature, except spelling. They concluded that proficiency in the basic skills taught in school is highest around 30 years of age, then declines for successive age groups.

Cognitive functioning for all variables was not at a maximum for groups of males and females less than 40 years of age. For most of the variables studied by Monge and Gardner, the largest mean scores were obtained by groups of much older subjects.

Problems in the research studies reported above revolve around the design of the studies. Cross-sectional studies may include for example, individuals who lived in the post World War I boom, those who experienced the Great Depression, those who lived during World War II, and those who experienced the Korean War and the internal political instability of the United States during the 1950's. The technological advances and changes in lifestyle over this period were of course, enormous. Because of such different experiences by subjects cross-sectional designs are criticized for weak external validity.

Critics of longitudinal designs however, cite internal validity weaknesses. There is often a problem with subject survival in longitudinal studies. In general, the healthier and most able subjects tend to survive better so that at the end of such a study outstanding subjects are over-represented in the research.

The differences between the characteristic findings of the two types of studies are that the cross-sectional studies produce evidence of a moderate but noticeable decline in performance across the life-span. Longitudinal studies indicate that abilities are maintained and may even increase into the seventh decade of life.

Baltes and Schaie [52] (1974) have structured a different design, known as the cross-sequential design, to resolve the major criticisms of both the cross-sectional and longitudinal approaches. Using the cross-sequential design, which incorporates cross-sectional and longitudinal elements, Baltes and Schaie seem to have disproven the previous belief in general intellectual decline. Their work produced two useful conclusions: (1) when a cross-sectional design is used, the younger group performs better than the older group; and (2) when a longitudinal design is used the kinds of skills acquired through education and acculturation such as verbal comprehension, numerical skills, and inductive reasoning, and the ability to organize and process visual materials increase with age, at least into the seventh decade.

1.2.2.1 Cognitive Styles

Cognitive style in conventional terms is no more than the characteristic way in which individuals use their minds. It is however, a powerful variable in the academic choices and vocational preferences of individuals, in their academic development, and how they interact in a learning situation. At least ten cognitive styles are frequently reported in the literature:

1. field independence vs dependence
2. scanning
3. breadth of categorizing
4. conceptualizing styles
5. cognitive complexity vs simplicity
6. reflectiveness vs impulsivity
7. leveling vs sharpening
8. constructed vs flexible control
9. tolerance for incongruous or unrealistic experiences
10. risk taking vs cautiousness

Most of the research literature focuses on field independence vs dependence. Field-dependent people are more influenced by the environment than are field-independent people, who are more "inner-directed." Research by Witkin and Berry (1975) has produced some conclusions about these learning styles. First, individuals remain fairly stable throughout life with respect to their place on the continuum between field dependence and independence in general, however, movement is toward field independence up to early adolescence, followed by a plateau to about fifty years of age. There is a movement toward field dependence around fifty years of age.

Secondly, cultures which emphasize sharp, clear role definition and social control seem to favor field dependence, whereas field independence is encouraged by cultures that emphasize self-control and independence.

Thirdly, field dependence is associated with cultures that follow strict child-rearing practices which encourage obedience to parental authority. Child-rearing practices that encourage individual autonomy and are tolerant of violation of parental authority are associated with field independence.

Cognitive style does not seem to be associated with intelligence. Field independents seem to favor the sciences and math however, and seem to have fewer learning problems than field dependents. The possibility that learning problems may be more a function of the way instruction is designed than of intelligence is of course, an important consideration in the development of computer-based instruction for adults.

1.2.2.2 Other Factors in Adult Learning Ability

Generally, it is noted that learning ability is a function of many factors. Guilford [56] (1971), for example, has developed a model that distinguishes between operations such as cognition and memory; products such as units and transformations; and content, such as figural and behavioral. Long [62] (1971) has indicated that other factors such as social, physiological, and personality variables should be considered in models of adult learning performance.

In recent years, adult educators, as well as gerontologists and psychologists have devoted growing attention to the association of variables other than age with learning ability. These include health, energy levels, sensory integrity, interests, motives, and class. The volume of literature on such factors as these is enormous and rapidly growing. The bibliography for this literature review provides an extensive list of sources for information on these factors.

1.2.3 Cognitive Theory and Cognitive Processes

Computer scientists have realized the importance of human factors for at least the past decade however, new areas of study on human-computer interaction have recently begun to develop. Memory, attention, problem-solving, and language are examples of the more prominent new areas of study related to human cognition. Additional emergent areas traditionally associated with cognitive psychology include human response time, the nature of errors, the time to learn, and self-reports.

Computer scientists and software developers have long employed information prescriptions for constructing human interfaces. Simplicity, naturalness, ease of use, consistency, feedback, and individualization are generally considered important, but the details for applying such general prescriptions are rarely specified. A systematic approach to constructing user interfaces must incorporate a review of empirical studies of cognitive processes in human interaction. Robert Allen, "Cognitive Factors in Human Interaction with Computer" (in Badre and Shneiderman [10], 1982) has provided such a review. Parts of his work are summarized below.

Three theoretical areas which have been frequently cited and are related to a wide range of issues in human-computer interaction are: short-term memory, long-term memory, and problem-solving.

1.2.3.1 Short-Term Memory

Theorists agree that the capacity of short-term memory is limited. The most well-known short-term memory model is probably that proposed by Miller [34] (1956). He proposed that short-term memory resides in a discrete buffer that contains 7 ± 2 items. However, much experimental evidence refutes this model. For example, Simon [44] (1974) found that the number of items it is possible to recall decreases as the complexity of the items increases. For example, it is possible to remember seven digits, but only three or four disconnected sentences. The single-buffer models of short-term memory have been replaced by models in which memory resources are dynamically allocated. According to such models, performance may be affected by the ways in which active processes share resources. Research continues in this area however, as some of the implications of these models have been questioned.

1.2.3.2 Long-Term Memory

The majority of current research models of long-term memory consider the effect of the organization of information to be an important characteristic. One type of memory organization process is known as "chunking". Associative networks have also been proposed as a type of organization process. Another organization process which has been identified is referred to as "schemas" (or frames, prototypes, or scripts). The processes associated with schemas are debated among researchers, but the value of schemas for organizing complex material is evident.

Applications for schema models are increasing as the field of human-computer interaction becomes more concerned with the mental organization of complex material. Various schema models have been employed in studies of users learning to program computers and learning to use text editors.

1.2.3.3 Problem-Solving

The activities associated with problem-solving are the focus of another approach to complex cognitive processes. While there are many different models of the mental processes which occur in problem-solving, the most widely used are the production-system model [36] (Newell and Simon, 1972). Such models postulate that when a given condition is achieved in short-term memory, a certain action or "production" will be initiated.

The validity of production-system models has been debated extensively. Reasons underlying such debates include the fact that the models are often based on verbal protocols in which subjects describe what they are thinking. Moreover, these models usually rely on the now out-moded single-buffer model of short-term memory and within that model are inconsistent about the capacity of short-term memory. For example, one production system model is based on the hypothesis that short term memory holds fourteen items.

Sections 1.2.3.4 through 1.2.3.7 will discuss some specific empirical studies involving cognitive factors in human-computer interaction. Section 1.2.4 will address important considerations for the application and investigation of cognitive factors in human interfaces.

1.2.3.4 Empirical Studies

Studies of cognitive factors in human interaction with computers relevant to this report have been divided into several discrete areas: directing a computer's actions, visual displays, and interaction with computers by voice and other modalities. Studies pertaining to areas more strictly focused upon the computer programmer's experience rather than the novice user (such as the typical user of computer-assisted instruction), will not be included in this report.

1.2.3.5 Directing a Computer's Actions

Studies examining user input activities have focused on several areas, including data-base access languages, command languages, menus and trees, natural language interfaces, and interaction with computers as "conversation".

In a study of errors made by users of two particular data-base access languages, Reisner [41] (1977) proposed a model of cognitive functioning. This model hypothesizes that a user generates a mental template of the structure of a query and then proceeds to determine specific parameters to be inserted in the template. In this model, user errors arise from the difficulty of translating natural language questions into the format required by the query language. Efforts to reduce this type of error have provided an explicit structure for the user to complete, as in Query-by-Example [48] (Thomas & Gould, 1975).

Additional problems for users of data-base search systems arise around the concepts of quantification and set membership. Few users are familiar with the formal logic concepts implicit in many data-base systems. In fact, for some types of tasks, natural logic has been found to be very different from formal logic. The possible solution of tailoring query languages to match an individual's problem-solving strategy is limited by the additional problem that many individuals are not consistent in their natural logic [45] (Thomas, 1976).

Several studies have produced conflicting results regarding the degree to which command languages should approximate natural language in structure and terminology. Consistency and rules in command languages appear to be very important. In particular, truncated command terms and fixed length abbreviations have been found to be easier for users to recall than contracted or variable length abbreviations [19] (Ehrenreich and Porcu, 1982). Thomas and Carroll [47] (1981) propose that individuals use schemas for command terms. Accordingly, they suggest that "congruence" is an important property for a command language (e.g. "open" and "closed", as semantic opposites, should be paired in the presentation of command terms.

Many of the results from studies on command languages are affected by reconstructive memory. That is, if a user from previous experience with command languages knows simple rules for generating commands, these will lead to correct inferences in a situation where the user can't recall a command directly from memory.

It is useful to realize that in addition to the reconstruction of command terms, several additional types of cognitive processes are required in using a command language. For example, the user must analyze the task, select a particular command, and enter the command into the computer. Different types of errors can be traced to different cognitive activities, and there may be interactions among the various cognitive activities. Most studies to date have been limited in focus to one or another of these processes.

Studies examining the use of menus and trees have shown that these design features incorporate several valuable psychological principles, such as allowing users merely to recognize rather than recall items. More specifically, hierarchial arrangements of information have been found to be especially appropriate for certain types of material (Brosey and Shneiderman [14], 1978) and for certain individuals (Broadbent & Broadbent [13], 1978).

The possibility of communicating with computers using wholly natural language has been the object of great debate. Proponents of natural-language interfaces cite the broad audience of potential users that could interact with computers without requiring extensive preliminary training. Critics of natural language interfaces point out that concise, instead of natural languages are more efficient for many types of problem-solving, and that the processing time and development costs of natural language interfaces are simply too high.

For the near future at least, natural language systems will be capable of dealing only with subsets of natural language. There are different ways in which a language may be restricted, including using only a limited vocabulary and restricting the syntactic constructions of queries. Studies (Kelly and Chapanis [29], 1977; Malhotra [31], 1975) have shown that for many applications a relatively small vocabulary (300 to 1500 words) is sufficient and when necessary, users can restrict their vocabularies. Malhotra [31] (1975) also found that users of his management information system naturally limited their queries to only 10 basic syntactic types, and in fact 55% of all sentences naturally composed were of only two types.

In comparing dialogue with a computer to conversations among people, some researchers have proposed that the intention and goals of the interaction are a more important focus than the literal meaning (Thomas [46], 1978). Several researchers are currently at work on the development of a framework for analyzing intention in conversations.

1.2.3.6 Visual Displays

The human factors literature has examined many aspects of visual displays, including physical considerations such as luminance, contrast, regeneration rate, and resolution. Recently there has also been work on visual fatigue and possible health hazards from the use of visual display units. Such physical issues are addressed elsewhere in this report. With regard to the psychology of computer-assisted learning, the increasing sophistication of displays prompts a need for research on how complex material may be most effectively presented and enhanced.

Visual display units are used to present text and graphics such as line drawings, tables, maps, forms, games, and pictures. In general, the research dealing with paper copies of graphs and tables and the perception of photographs (see Biederman [11], 1982) is applicable to the use of graphics in computer-assisted learning.

The perception of graphic displays must be examined in the context of other mental activities. From a broad perspective, some general cognitive principles may be applied with respect to the conditions under which visual processing affects task processing capacity. Kahneman [27] (1973), and Treisman & Davis [44] (1973) consider this possibility in their respective papers.

Cognitive processing involving text displays may be examined at several levels, including the search of a visual display for a single letter or word (Hirsch [24] (1981). The most common activity involving text displays however, is reading. Several aspects of displays affect the ease with which text is read including legibility of text (Bouma [12], 1980), spatial cues, typography (Coke & Koether [15], 1981), and color (Engel [20], 1980). The importance of a logical structure in the text itself has also been noted (Wright [51], 1977).

1.2.3.7 Interaction with Computers by Voice & Other Modalities

Interaction with computers by voice has been until recently, relatively unused in comparison to interaction by text. This has occurred primarily because it has been easier to store and manipulate text than voice. The traditional associations of text with formal documentation, and voice with informal interaction have in part perhaps, also contributed to the lag in the use of voice interaction with computers. The user's cognitive capabilities in dealing with written and spoken information should emerge as a growing area of study, as current technology is overcoming the limitations of interaction by voice. If a spoken unit (such as a dictated letter) is stored on a computer, various strategies may be implemented for high-speed presentation of the speech and for rapidly accessing different parts of the letter. Clearly the effectiveness of different methods will depend on how humans can best process the information.

Voice and text may be used together to enhance the best features of each. Studies have shown that the use of two different sensory modalities for input may help to reduce attentional demands and improve sensory buffering (Hartman [23], 1961; Hsia [26], 1977). An example of how the use of different modalities might improve user performance involves text editors. Typical text editors require text entry and command entry with a keyboard. A common error is that commands are entered as text and text is entered as commands. Limb [30] (1981) has suggested that this type of error could be minimized by entering commands in voice and text by means of the keyboard.

Many of the arguments for and against natural language interfaces may be applied to the concept of full speech recognition. The utility of the limited speech recognition which is currently available (on a much wider scale than are full speech recognition systems) has been studied. Connolly [16] (1979) for example, in studying an air traffic control task, found that voice input of selected words resulted in 64% fewer errors than entering equivalent coded messages on a keyboard although he found no advantage in the rate of entry.

Speech synthesis is another area of current study. In general, the work to-date has focused on the comprehensibility of synthesized speech. Results show little difference in comprehensibility between synthesized and natural human speech (Pisoni & Hunnicut [39] 1980). Michaelis and Wiggins [33] (1982) discuss at length, many of the issues in speech synthesis.

While the studies reported herein are not limited in focus to computer-assisted learning, their results are directly applicable to the development of computer-assisted instructional systems. Studies which relate to more physical aspects of human computer interaction will be covered in Section 1.3 of this paper.

1.2.4 Implications

In summary, many interesting and potentially valuable studies concerning cognitive aspects of human interaction with computers have already been carried out. As the sophistication of computers and software continues to increase, studies of cognitive factors are likely to continue and to grow in relevance. However, the development of scientifically valid theories and principles is a time-consuming and extremely difficult task. The complexity of creating satisfactory models is enormous, but the benefits from this challenge will have tremendous significance to the development of instructional software and hardware designs.

The complexity of the cognitive processes makes research difficult. Although research and theories attempt to isolate specific aspects of performance, naturally occurring cognitive processes are embedded in a continuous stream of mental activity as the user responds to his/her complex environment. Additionally, because human cognition is an active area of research, there are many different models and practically supported hypotheses which must be evaluated and selected among before the cognitive ergonomics researcher can construct and carry out new studies.

Beyond cognitive processes, there are several other important psychological issues in human interaction with computers. Cooler [17] (1979) and Sheridan [43] (1980) have for example, discussed computer users' motivations, fears, and social pressures. Such psychological factors can have not only direct effects upon human-computer interaction, but can also combine in complex ways with cognitive factors. Rabbitt [40] (1979) for example, found that a person in a state of emotional arousal may perform poorly on tasks which require complex mental processing, but not change performance on simple tasks.

The works of two noted authors in particular Alfred Bork and Greg Kearsley are useful in translating the voluminous research pertaining to the psychology of computer-assisted learning into practical recommendations for the design, development, and application of computer-assisted learning.

Bork suggests that the most valuable aspect of the computer in education is that it allows learning to be made interactive, with students cast constantly as participants in the learning process rather than as spectators. Psychologists agree that the best feedback comes immediately after the event. Bork recommends the creation of interactive computer programs which enable the student to converse through the computer program, with the authors of the material. He believes that visual information should play a critical role in this "conversation" if the needs of all students are to be met.

According to Bork, among the attributes of the computer most valuable to the adult learner is the ability of the computer to individualize, presenting alternate learning materials for a student who does not learn with a particular approach. The learning experience can be unique for each student; tailored to the needs, desires, and moods of that student.

Bork cites Robert Karplus, who suggests that experience is the first stage of the learning cycle and, touts the ability of computer-assisted learning to amplify everyday experiences as well as to create worlds that are not available in convenient form for students to explore. Thus he says "we can create realms of experience", with the hope of enriching the formal learning environment to follow and with the hope of building up student insight and intuition about physical processes thay may later be described in other more formal ways.

The ability of the computer to make individualized pacing convenient and commercially practical is another important feature noted by Bork. Going beyond the improved learning rates with self-pacing noted by cognitive researchers, self-pacing can allow for use of the same program by students with very different backgrounds. Some students may spend large blocks of time with remedial material before moving forward in the main instructional program. The computer can allow for this type of flexibility.

Additional comments by Bork draw attention to the use of the computer in moderating personal factors ... "the computer has no prejudices" toward the better students, never tiring of the problems of students struggling to learn a particular piece of material.

Greg Kearsley focuses on motivational aspects of computer-assisted learning. He praises the ability of well-designed computer programs to provide extrinsic motivation by building contingencies which facilitate the completion of self-study materials.

With regard to producing intrinsic motivation, Kearsley believes that the design of self-study materials will have a major effect on the degree of motivation created. Design factors such as length of lessons, degree of modularity, and use of color and graphics in conjunction with text are important in influencing the learner's attention.

Kearsley also notes that the possibility of using computers to learn at the employee's work location is sometimes an advantage and sometimes a disadvantage. The advantage is that the employees can arrange their work schedules to learn what they want, at times that are convenient for them. The disadvantage is that the work place is frequently full of distractions or interruptions, such as phone calls, visitors, or customers. For these reasons, self-study at the work place may work best for people such as managers and professionals who can control their environment, rather than those who cannot, such as secretaries and clerks.

Lastly, Kearsley cites the many unique virtues of computer-based simulations. Simulations allow people over a very short period of time, to acquire considerable experience with certain tasks or situations. In addition, the experience is gained in a "safe" enviroment, especially important when the task requires learning how to maintain or operate dangerous or vital equipment.

Kearsley and other authors such as Goos and Hartmanis, and Salvendy, in particular, have written and collected many papers which provide highly specific recommendations to designers of computer-assisted learning, based on research in cognitive ergonomics. The application of such recommendations will serve both to improve the quality of computer-assisted learning and to provide new ground for further research into the interaction between humans and computers.

1.3 Research Findings in Computer-Aided Learning

In conducting a meta-analysis of the effects of CAL, Kulik [98] found that CAL instruction produced somewhat better score results and favourable ratings of the material covered than did conventional instruction. There was a statistically significant positive difference in attitude towards the computer for those using CAL, and substantial time-savings in instruction were also reported.

Montague [101] describes the benefits found in computer use for a Navy apprentice training course as reduction in course completion time, the ongoing possibility for re-development of courses, course offerings on-demand, real world representation, and remote site use. However, no substantial effectiveness or efficiency differences compared to conventional methods were found.

Morrison [102], in his experiment on print-based versus computer-based job performance aids ("embedded training") for recall of army tank crew tasks, found that for first trials on simpler tasks the computer-based aid resulted in a more accurate performance, however, there was no difference for the more complicated tasks. There was no significant difference in timing related performance. In terms of preference, 75% preferred the computer-based job aid because of a greater facility in reading the screen, the faster speed of the computer, and greater ease in following the steps. The task involved a step-by-step procedure, each step of which required the soldier to respond to questions on the phase of operation or status of controls and indicators, the responses to which determined the next step.

Tait & Hughes [107] investigated the use of a computerized multiple-choice question system (MCQ) in pharmacology in terms of whether students with more aptitude spent more time using the computer-based system, and whether spending more time in this way lead to higher examination marks. They found that those with more aptitude did not necessarily spend more time on the computer however, time spent did positively impact score, but with a diminishing effect over time.

Gastkemper [89] examined the effect of integrating CAL and videodisk for use in training for the observation of non-verbal behaviour in the field of psychology. The process involved viewing videotapes of situations as a whole and split-screen close-ups, identifying characteristic elements of behaviour of one individual and labelling the relation of this individual to the other, and the intensity of this relationship. Students' ratings of this approach versus the traditional approach were very favourable, with two thirds to three quarters of the students rating it as equal to or better than the conventional method. The overall conclusion was that more extensive use should be made of CAL.

1.4 CAL and Ergonomic Factors

1.4.1 Introduction

Regardless of the application or whether the simulation capabilities of CAL are used, or any of the other forms of CAL instruction, such as tutorials, games, drill and practice, the most crucial element of CAL development is the design of the courseware with respect to the user. Without it, the pedagogical gains are non-existant, as they would be with any badly designed course material using the traditional method. From courses offered in the Military, Montague noted problems associated with CAL instructional design as including:

> "lack of job-relevance, indiscriminate use of previously existing instruction, failure to carefully select instructional methods, and testing what could, rather than what should, be tested. In addition, evaluation of training received little emphasis." [101, p. 90]

He notes further deficiencies in CAL assigned personnel who are,

> "relatively untrained and inexperienced in teaching and training, and in the fundamental knowledge needed to determine the appropriate forms of instruction." [101, p. 90]

A number of elements are generally considered essential to successful courseware design. Any CAL development should address these to ensure that the resulting product is favourably received by its users. These elements are discussed below.

1.4.2 Advantages and Disadvantages of CAL

One of the often cited advantages of CAL is the opportunity for providing individualized instruction. The user is free, first of all of emotional or other involvement with another personality (the instructor). The user, without recrimination and in private, can make mistakes, re-do activities as often as desired, and proceed at a pace suitable to that individual. Feedback is instantaneous, and thus presumably more effective. An advantage noted by Kidd & Holmes and attributed to Fernand Marty's work on his elementary French PLATO program is a "higher level of concentration for longer periods of time with a resulting increase in retention." [96, p. 91] [96] [98]

From the organization's point of view, the loss of expertise when an individual leaves is minimized, since training material can be prepared tapping the source, and used in future training sessions to maintain continuity on the job. (Note here the possible application of Artificial Intelligence Techniques for structuring this process). This facilitates training of staff on an on-going in-house basis without for example, the disruption of normal work schedules [101].

Notwithstanding the benefits of CAL, its current deficiencies must also be noted. The system cannot account for all the possible answers to a problem. It also cannot feel or sense discomfort or lack of understanding in the user, and adjust accordingly to assuage the anxieties of the user. At this time, it is not and cannot be a replacement for the human interface between trainer and trainee.

1.4.3 Issues

1.4.3.1 Timing

One of the issues that needs to be addressed in this context pertains to timing. Such things as the length of the lesson(s), how many lessons should form a session, how many sessions should form a course, the number and length of tests - all need to be established. The optimal timing between sessions must also be defined.

The timing of these is important from the user's perspective, so that fatigue, boredom and information overload are not evoked in the use of CAL. Additionally better retention is found to take place when training is spread over a period of time rather than concentrated in "chunks". However, allowing too large a time interval to elapse between sessions results in forgetting in a few [94].

Other timing issues pertain to the system itself, in terms of downtime, response time, delay and frequency. Kearsley [85] cite references which note that it is not so much the length of the delay which affects the user, but rather a variability in response time.

1.4.3.2 Reliability of the System

Frequent breakdowns of an unreliable system result in frustration for the user and the making of the interaction with the computer an unpalatable experience. [94, p. 78].

1.4.3.3 Course Content

For the same reason as above, it is important that the course not contain overly repetitive activities or material. This is especially true for users who have mastered the material. Boredom and frustration are sure to ensue if already mastered material is repeated and presented, and thereby motivation and hence learning effectiveness is decreased. [90] [91] [93] [94] [98] [104] [105]

The content of the lesson, the use of examples (using examples, and a variety of these, promotes learning), and the content of the examples should be representative of and pertinent to the material to be mastered.

1.4.3.4 Course Structure

The logical structure and sequencing of the information content and flow is crucial from the user perspective, if learning is to be achieved. A failure to achieve this will result in confusion, lack of comprehension and frustration which in turn inhibits knowledge acquisition and retention. Horn et al., as a pedagogical technique in designing courseware, suggest the use of

> "review and preview, introductions at each stage, recaps and summaries, tree diagrams to show links, comparison and contrast charts, summary tables, review tests after short segments, schematic paths of possible routing options." [93, p. 12] [88] [93]

1.4.4 Media Use

Amongst the other issues to be considered are the types of media to be employed (computer; text; video; discussion; slide/tape, etc.) and how these will be integrated into the overall course. A smooth transition from one medium to another is important for continuity and consistency, and so as not to confuse the user. At the same time, consistency of scoring must be maintained across the media. [94]

1.4.5 Ease of Use

A CAL program should cut across computer expertise levels, such that novice and experienced users alike can easily avail themselves of the program and use it readily, i.e. the use of the computer should be "transparent" to the user except where computer training is an objective of the training. Operating instructions should be clear and comprehensible, from "sign on" through "sign off". The user should know what action or information input is required and when.

The user's initial, impressions and responses to this form of instruction determine its eventual success as a training tool. As noted above, frustrations must be minimized if learning is to be pleasurable and effective. [1] [2] [17] [87] [88] [103]

1.4.6 Screen Display

To maintain interest and encourage learning, screen displays should be as interesting and varied as possible, without being overly distracting. This can be done through the use of colour, graphics, animation, highlighting, flashing texts, varied texts and sizes, various media, etc. Motion through animation, highlighting and flashing, as well as graphics, can be used to prompt and direct the attention of the user, and for emphasis. While neither colour nor graphics have been unequivocally proven to increase learning effectiveness, a degree of preference for these has been noted. [1] [2] [6] [7] [11] [17] [87] [88] [102] [103] [107] [113]

Because there are limitations to human information processing capabilities, care must be taken in determining the quantity of information to be displayed on the screen. The screen should be easy to read and free from clutter.

Studies cited by Hathaway [102] gave 80 characters per line, double spaced as the desired text display density. It was found that scrolling text 20% faster than the preferred rate produced the fastest reading rate without damage to comprehension. A mixture of upper and lower case text resulted in a faster reading rate than solely upper case lettering, however, the latter was read with more accuracy. The actual size of the text was optimally defined at .0070 radians. Overlays, split screens, scrolling, etc. can also be used to enhance the flow of course material and assist in the dissemination of learning elements. [92] [94] [100] [104] [105]

1.4.7 Interaction

The use of the program should not require typing skills. Using function keys, cursor keys, or one letter or number commands is a way to avoiding this requirement. Other devices which may be employed are light pens, "mice", touch panel screens, voice. [94] [97]

In designing the courseware, the aim is to achieve active participation by the user. As such a question/response/feedback approach is usually employed. To minimize guessing, a free-response format is often preferred, but this makes evaluation by the system more difficult. As noted earlier, not all possible answers can be incorporated into the system. [93] [94] [97] [110]

To give support to the user, a "hotline" is advisable for an immediate response to problems encountered with the system. Likewise, a facility for message exchange between user and instructor is desirable. The program should also indicate to the user the stage in the lesson she/he has reached and what and how much more is to come. [93] [94]

1.4.8 Level of Difficulty

The courseware should not be so difficult or easy as to reduce the student's motivation. Ideally, the user should be able to vary the level of difficulty to suit his/her preference or mastery of the material, and to switch between levels as desired. Pre-tests can be used to determine the level at which to begin a lesson, and post-tests to determine progression from there. The capability of switching between levels at random gives rise to problems of logical sequencing and progression, and of maintaining position in the levels and of scoring. [88] [90] [94] [97] [106] [107]

1.4.9 Control

The user should feel in control of the program. She/he should be able to move backwards and forwards in the lesson and to skip over material as desired, without the system losing track of scoring and position in the lesson. There should be the facility to review and change answers during the lesson time. The user should be able to progress through the lesson at an individually defined rate, and dictate rest periods and duration. It is important that the user not become overly fatigued or stressed during the session and thus have learning impeded. As such, the user should be able to exit from the program at any time, and to restart at the point where it was left off. [87] [90] [92] [94] [98] [107] [111]

1.4.10 Error Checks

The system should prevent syntactic and entry errors outside the acceptable range from being put in, for example numeric input in place of alphanumeric input and vice versa, and should accept upper or lower case text response. Incorrect input should prompt a listing of the acceptable range. Penalties should not be given for errors in spelling or grammar, in computation (unless these are the lesson), and allowance should be possible for nearly right or synonymous answers. [88] [94] [103] [105]

1.4.11 Scoring

It is important to provide appropriate feedback, at the appropriate time, in a consistent and unambiguous way. Feedback is crucial to reinforce positive learning and to correct negative learning, such that it is not demoralizing but rather motivating. Attempts should be made to minimize the possibility for guessing, and to provide hints towards the solution when difficulties are encoutered by the user. Scoring should be capable of recording by frequency of correct answers, by topic category, by timing and number of tries during the session and so on.

Testing should be integrated to allow users to monitor their progress and to enhance reinforcement and retention. Tait notes that,

> "questions must be sufficiently difficult that the student makes some mistakes; secondly, the feedback should be aimed at helping the student who is well on the road to understanding; and thirdly there must be tasks which provide opportunity for the student to test his recently acquired understanding." [116, p.17] [1] [2] [3] [7] [8] [11] [12] [20] [87] [88] [89] [103] [104] [107] [108] [116]

1.4.12 Assessment & Remedial Channelling

Based on performance in the session and on tests, the user should be channelled to the appropriate remedial material or to more advanced material. There is some indication that this assessment should be on demand by the user rather than on a continual basis. The ideal program would develop a profile of the user's progress from the various sessions, and adjust the material presented to the user accordingly. This concept is described in Horn, et al., in which information mapping,

> "a method of organizing categories of information and of presenting them in formats that communicate quickly with the user", [103, p. 117]

is used to develop a system which facilitates individualized instruction presentation defined by either the user, the computer, or both. [103] [104] [116] [118]

1.5 Ergonomic Factors of Interactive Computer Systems

1.5.1 Objectives

This section presents some ergonomic principles and criteria for designing computer-aided learning (CAL) systems. It comprises two principal parts. The first part identifies principles, guidelines, or criteria that have been proposed by different authors for designing friendly software. The second part examines in more details six ergonomic criteria that are particularly important for system friendliness. Systems based on such criteria should be easy to learn, to remember, and to use, and be "fun". They should thus contribute to user performance, comfort, and satisfaction.

1.5.2 Principles for Designing "Friendly" Software

Many principles, guidelines, or criteria have been proposed for designing "friendly" software (see Figures 1 to 12). Several of them remain ill-defined and insufficiently operational (e.g., consistency, redundancy). Some are of great value but not measurable (e.g., Figure 3: "promote the personal worth of the individual user"). Finally, some may be acceptable from an intuitive point of view, are not based on experimental data (e.g., Figure 8: "avoid redundancy").

User engineering principles.

First principle: Know the user.

Minimize memorization.
- Selection not entry
- Names not numbers
- Predictable behavior
- Access to system information

Optimize operations.
- Rapid execution of common operations
- Display inertia
- Muscle memory
- Reorganize command parameters

Engineer for errors.
- Good error messages
- Engineer out the common errors
- Reversible actions
- Redundancy
- Data structure integrity.

Figure 1 User Engineering Principles for Interactive Systems (Hansen, 1971) [123]

Provide a program action for every possible type of user input.

Minimize the need for the user to learn about the computer system

Provide a large number of explicit diagnostics, along with extensive online user assistance

Provide program short-cuts for knowledgeable users

Allow the user to express the same message in more than one way

Figure 2 The Design of Idiot-Proof Interactive Programs (Wasserman, 1973) [123]

Know the user population

Respond consistently and clearly

Carry forward a representation of the user's knowledge base

Adapt wordiness to user needs

Provide the users with every opportunity to correct their own errors

Promote the personal worth of the individual user

Figure 3 Design Guidelines for Interactive Systems (Pew and Rollins, 1975) [123]

Introduce through experience

Immediate feedback

Use the user's model

Consistency and uniformity

Avoid acausality

Query-in-depth (tutorial aids)

Sequential - parallel tradeoff (allow choice of entry patterns)

Observability and controllability

Figure 4 Design Guidelines for Interactive Systems (Gaines and Facey, 1975) [123]

Simple. Project a "natural," uncomplicated "virtual" image of the system.

Responsive. Respond quickly and meaningfully to user commands.

User-controlled. All actions are initiated and controlled by the user.

Flexible. Flexibility in common structure and tolerance of errors.

Stable. Able to detect user difficulties and assist him in returning to correct dialog; never "deadending" the user (i.e., offering no recourse).

Protective. Protect the user from costly mistakes or accidents (e.g., overwriting a file).

Self-documenting. The commands and system responses are self-explanatory and documentation, explanations or tutorial material are part of the environment.

Reliable. Not conducive to undetected errors in man-computer communication.

User-modifiable. Sophisticated users are able to personalize their environment.

Figure 5 Interface Design for Time-Sharing Systems (Cheriton, 1976) [123]

1. Simplicity
    - 1.1 Few keywords - few commands
    - 1.2 Simplicity of input
    - 1.3 Short commands
    - 1.4 Simple commands
2. Clarity
    - 2.1 Hierarchical structure
    - 2.2 Functionality
    - 2.3 Homogeneity
    - 2.4 Problem orientation
3. Uniqueness
    - 3.1 Determinism
    - 3.2 No undefined states
4. Comfortable language
    - 4.1 Powerful commands
    - 4.2 Flexibility
    - 4.3 Short dialog
    - 4.4 Full use of data structure
5. Other comfort
    - 5.1 Input comfort
    - 5.2 Interruption
    - 5.3 Output language - clear, short, understandable system messages
    - 5.4 Additional comfort: function keys, acoustic signal after output transmission, highlighting and/or underlining.
6. Evidence and reusability
    - 6.1 Evidence
    - 6.2 Help functions providing information on the system state, the presently used function
    - 6.3 Reusability - former commands and output (or part of output) reusable for input
7. Stability
    - 7.1 Error handling
    - 7.2 No compulsory situations
8. Data security

Figure 6 Design Criteria for Documentation Retrieval Languages (Gebhardt and Stellmacher, 1978 [123]
N.B. For a matter of brevity the explanation given by the authors for each point has been taken out.

Forgiveness - ease in repairing errors

Segmentation - layered approach

Variety - choice of style

Escape - break out of danger

Guidance - direction and learning

Leverage - flexible, powerful features

Figure 7 The Human-Machine Interface in a Computerized Conferencing Environment (Turoff, Whitescarver, and Hiltz, 1978) [123]

1. Use terse "natural" language, avoid codes, allow abbreviations.
2. Use short entries to facilitate error correction and maintain tempo
3. Allow single or multiple entries to match user ability
4. Maintain "social element" to the communication
5. Permit user to control length of cues or error messages
6. Error messages should be polite, meaningful and informative
7. Give help when requested or when users are in difficulty
8. Simple, logically consistent command language
9. Control over all aspects of the system must appear to belong to the user
10. Avoid redundancy
11. Adapt to the user's ability
12. Keep exchange rate in user's stress-free range; user can control rate

Figure 8 Ground Rules for a "Well-Behaved" System (Kennedy, 1974) [123]

Boredom, a consequence of improper pacing
Panic, the consequence of unexpectedly long delays
Frustration, the result from an inability to easily convey intentions to the computer and, consequently, eliciting either an unexpected response, or none at all
Confusion, the consequence of perceived structure being overwhelmed by detail
Discomfort, the consequence of an inappropriate physical environment for the graphics work station

Figure 9 Psychological Blocks that Often Prevent Full User Involvement in an Interaction (Fohey and Wallace, 1974) [113]

1. Operator "channel overload"
2. Operator boredom
3. Lack of motivation
4. Inadequate instructions for handling emergencies

Figure 10 Psychological Factors that Can Cause Errors (Martin, 1973) [118]

a. Display a small amount of information at one time
b. Have an idea per display
c. The operator response should be short
d. The computer should always respond to the operator
e. Use formats designed for clarity
f. Strive for similarity
g. Avoid difficult words and characters
h. Provide an easy means for correction
i. Make instructions to the operator standout
j. Cleanup the screen when possible
k. Make it easy for the operator to ask for help

Figure 11 Principles for Designing Screen Formats (Martin, 1973) [118]

1. Know your subject
2. Know your audience
3. Maintain the user's interest
4. Communicate visually
5. Lever the user's knowledge
6. Speak the user's language
7. Communicate with metaphors
8. Focus the user's attention
9. Anticipate problems in the user's perception
10. If you can't communicate it, don't do it
11. Reduce the user's defensiveness
12. Give the user control
13. Support the problem-solving process
14. Avoid frustrating the user
15. Help the user cope
16. Respond to the user's actions
17. Don't let the user focus on mechanics
18. Help the user to crystallize his thoughts
19. Involve the user
20. Communicate in specifics, not generalities
21. Orient the user in the world
22. Structure the user's interface
23. Make your product reliable
24. Serve both the novice and the experienced user
25. Develop and maintain user rapport
26. Consider the first impression
27. Build a model in the user's mind
28. Make your design simple
29. But not too simple
30. You need vision

Figure 12 Principles of Friendly Software Design [114]
(Heckell, 1982) [114]

1.5.3 Ergonomic Criteria for User Friendliness

It is generally agreed that interactive systems should have the following qualities in order to be user friendly: they should be simple, logical, natural, consistent, transparent, provide feedback, etc. Because of new enabling technologies, systems should also permit the direct manipulation of objects on the display and be learnable by exploration. Finally, the interaction with a computer should bring pleasure to the user and therefore, the system should be "fun" to use. The purpose of this section is to present six ergonomic criteria that are particularly important for the friendliness of computer systems. They are the following: direct manipulation, exploration, feedback, consistency, transparency, and pleasure.

1.5.3.1 Direct Manipulation

There exist new human-computer interfaces called "direct manipulation" or "object-oriented" which seem remarkably powerful. They "are generally regarded as more satisfying and easier to use, and should find broad application". [128, p.1] They have three basic characteristics: a "continuous representation of the object of interest, physical actions or labelled button presses intead of complex syntax and, rapid incremental reversible operations whose impact on the object of interest is immediately visible". (Shneiderman 1982, p.251: see [115]; [124] for a review). They are enabled by three different technologies: "raster graphics, especially bit-map displays, for the presentation of complex manipulable images; pointing devices, especially the mouse for rapid analogic input; and computing power dedicated to reacting dynamically and meaningfully to the user's actions. [128, p.2]

These interfaces appear to have the following virtues:

1. Novices can learn basic functionality quickly, usually through a demonstration by a more experienced user;

2. Experts can work extremely rapidly to carry out a wide range of tasks, even defining new functions and features.

3. Knowledgeable intermittent users can retain operational concepts.

4. Error messages are rarely needed.

5. Users can see immediately if their actions are furthering their goals, and if not, they can simply change the direction of their activity.

6. Users have reduced anxiety because the system is comprehensible and because actions are so easily reversible". (Shneiderman, 1982, p.251 see [115])

These interfaces which exist in systems such as the Xerox STAR, the Apple McIntosh, and Bill Budge's Pinball Construction Set provide users with a visual environment that is generally composed of familiar office objects represented by icons. One does not have to remember the existence, name, or location of the objects. Furthermore, by definition, these interfaces allow users to carry out tasks by directly manipulating objects on the screen, generally through the mouse, instead of typing command names or selecting commands from menus which are indirect ways of working. For example, one will move a file icon over the trash can icon on the screen to delete a file. So, users do the job themselves instead of having it done through a mediator. This directness and visuality (several authors insist on the importance of communicating visually with users) [114] [128] seem very appealing to users.

1.5.3.2 Exploration

With direct manipulation user interfaces, interactive systems can have the quality of being explorable, i.e. learnable by exploration. Thus, a new criterion (explorability) is set for evaluating the ease of learning and use of interactive computer systems.

Exploration is a learning mode whereby one learns a system first by interacting with it. No tutor, documentation, or any external help is provided to the subject. The only way to learn the system is through the feedback coming from the dialogue with the system.

Exploration corresponds to a natural way of learning for many people which is learning by doing (i.e. directly using the system) rather than by reading (i.e. concentrating first on the user documentation). Indeed, many system users are eager to "do" because they can thus be "physically" active, be confronted with a concrete situation, feel more involved in learning, and benefit from simulated interaction. They can also set their own goals, self-initiate problem-solving, control their learning, etc. Conversely, reading computer documentation is rarely a thrilling experience. It is not interactive, and the documentation is often voluminous, incomprehensible, and difficult (e.g., Carroll 1984; Robinson & Knirk 1984; Scharer 1983 [120]). Furthermore, it is often out of date and expensive.

Presently, there exists explorable systems relying on icons for representing objects, on the mouse for manipulating them, and on menus for displaying commands that are available (e.g., STAR, McIntosh). Even though these systems are explorable from the very first use, they still present serious difficulties for the learners. An experimental study [120] showed that people encountered the following problems when they explored a personal computer: they may get temporarily confused, lost, or blocked in some state of the system; or they may misinterpret the system's responses, be unaware of the repercussions of what they are doing, and create tangles of problems that are particularly difficult to diagnose. They had tremendous difficulty with error recovery, and were easily side-tracked when trying to complete some tasks. Also, they may use non-optimal procedures, forget parts of their learning and not discover all the capabilities of a system by having no way of testing the completeness of their knowledge. Furthermore, they may have to cope with flaws and inconsistencies in the system. The effect of this can be very bad, even catastrophic, for the users: wastes of time, frustration, blame for system, blame of oneself, abandonment of work, etc.

To palliate some of these problems, we have proposed several design features for improving the explorability of systems and making exploration a productive and pleasurable experience.

The system should be robust and have safeguards against the deletion of anything important. It should permit the subject to backtrack or undo an action or a group of actions that have some undesired effect; error recovery, which was a major problem for "explorers", would then be facilitated. It should also permit one to easily get out of any situation and go to a recognizable location in the system. Furthermore, to support risk-taking, it should rapidly save what is done as well as permit subjects to make simulations or excursions in the system without spoiling their current work. To facilitate learning transfer, the consistency of the system should be ensured; special attention should be given to the grouping and spatial arrangement of commands, icons, etc. in order to draw the subject's attention to differences between them. To tackle the overwhelming information problem, it has been astutely proposed (e.g., by Carroll 1983) to progressively disclose the system's functions to the subject. More research is needed on this topic.

To help an "explorer" remember procedures a history key or function could give access to a list of his/her actions with the system, and show their relations and outputs. The architecture of the system, icon representation, icon and command names, relations between seemingly independent objects, etc. must be transparent. The system feedback ought to be rapid, meaningful, and clearly related to one's action.

1.5.3.3 Feedback

The system feedback must be rapid, meaningful, and directly related to an action so as to allow a user to make clear action-response associations. This is of prime importance in learning environments. The feedback can be visual, auditory, or both according to the situation. Generally speaking, the auditory feedback should be short, i.e. not be prolonged until the next user action. In most of the cases, a "bip" will suffice.

Feedback should be consistent from one command to another, except in cases where the designer wants to draw the user's attention to some special operations. This consistency applies to the number, type, location, duration, etc. of the feedback. Finally, prompts or error messages should be constructive, supportive, and explicit, not condemning, confrontive, or too laconic. The system should never "dead-end" leaving the user confused and without recourse. [114] [118] [123]

1.5.3.4 Consistency

Authors agree that consistency is desirable in interactive systems. Indeed, the concept or its equivalence (e.g., uniformity, . homogeneity, similarity, predictability) appears in almost all lists of guidelines proposed by different authors for designing friendly computer systems. [112] [118] [123]

The best "definition" is that proposed by Young, 1981. [129] It says that "... a machine should be regarded as inconsistent if the user exposed to certain aspects of its behavior is led to form expectations about other aspects, which the machine itself then violates". (p.81) It is important to note that the concept is defined here from a practical or user point of view rather than from a strictly logical one.

Consistency allows the user to form expectations about system behavior, make predictions about it, transfer his/her learning from one part into another, and rapidly develop automatisms that are essential for greater efficiency. [125] It should thus contribute to making a system easier to learn and use, and to reducing users' frustrations. Finally, it should help to build a good image of a system which can be crucial in the market place.

Consistency is a complex concept that is difficult to tackle. As the designers of the Xerox STAR system put it: "... it is perhaps the single hardest characteristic of all to achieve in a system". [126] It is so because of frequent conflicts between different elements of the system and inevitable compromises which must be made (e.g., when A cannot be consistent with B and C simultaneously). What makes things more complicated is that inconsistencies may be desirable in a system to draw the user's attention to unusual or critical operations. Indeed, they can be an effective way of breaking routine actions and forcing the user to pay particular attention to the next operation and its consequences. Furthermore, practical considerations, not purely logical ones, would determine whether or not there are inconsistencies [127].

Over the last two years, a rigorous method has been developed for locating, describing, and classifying inconsistencies of user interfaces and making predictions about user's difficulties and errors. [120] [122] This method is still under development, but can already be used by designers. It consists of four steps:

1. Formally describe the user interface. This description depicts the structural and operational aspects of the system. It covers the normal situations wherein there is no anomaly in using the system as well as the error and error recovery situations.

2. Divide the interface into three major components which can also be divided at least into 2 levels each. This taxonomy has been proposed by Moran [119]. It is very useful for classifying the different parts of an interface.

    a. Conceptual component:
       (i) task level
       (ii) semantic level

    b. Communication component:
       (i) syntactic level
       (ii) interaction level

    c. Physical component:
       (i) spatial layout level
       (ii) devices level

3. At each level, locate all the possible issues that can be at the origin of some inconsistency (e.g., at the syntactic level: number of arguments, place of the arguments, command recursion, range of recursion, use of default option, etc.).

4. Systematically compare each pair of elements of the system (e.g. 2 commands, 2 prompts, 2 menus) over all the issues that have been identified at the precedent step. [120] [122]

1.5.3.5 Transparency

At any time, the user should know where he/she is in the system, what to do to enter and exit a mode, how to get out of any situation, how to backtrack or undo an action, etc. He/she should instantly be able to recognize icons, understand terms used for command, menu title, mode, and interpret any prompt presented on the display.

1.5.3.6 Pleasure

The interaction with a computer should be interesting and enjoyable for the user, and correspond to a "pleasureable engagement" (Laura Brendel). One author in particular, Malone [116] [117] has been interested in this topic.

Malone systematically studied more than 100 people playing computer games, looking primarily at what made the games "fun". After having identified what people liked about several games, he constructed different versions of these game by taking out, one at a time, features that were presumably motivational. Then he conducted psychological experiments to evaluate the importance of each feature. From these features, he developed a set of guidelines for designing highly motivational educational computer games. These guidelines could be used in making educational activities more fun, and also, in designing non-educational computer games, or in making other computer programs fun to use.

Table 1 presents various features of computer games that can be incorporated into user interfaces. It appears that challenge, fantasy, and curiosity are the major factors for enjoyable interfaces. This table should be viewed as a checklist of ideas, as Malone recommends. "Certainly not all the features will be useful in all interfaces" [p.68] The author concludes with this suggestion: "I think that many user interfaces could be improved by systematically considering the inclusion of features such as multiple layers of complexity, productive and involving metaphors, and useful sounds and graphics". [p.68]

1.6 Conclusions

The most important consideration in CAL development, irrespective of application, must be the user. Kearsley & Hillelsohn [94] note that well designed courseware is a necessary but not sufficient criteria for successful CAL. Success depends largely on user acceptance and response to this mode of instruction. For this reason, initial impressions are important since bad first experiences are likely to constrain subsequent use. By taking into consideration the elements discussed above, some attempt is made to address this issue and hopefully, to avoid permanent catastrophic imprinting in the mind of the user. There is the potential for very sophisticated learning with this mode of instruction, providing it is favourably perceived at the early stages of use.

The air traffic control area is especially suited to the use of CAL in training. It is an area that could capitalize readily on the simulation capabilities and integration of videodisk with computer which CAL instruction and technology permits. As such, the elements for effective CAL are as appropriate and relevant in the air traffic control area as it is elsewhere.

I. Challenge

   A. Goal. Is there a clear goal in the activity? Does the interface provide performance feedback about how close the user is to achieving the goal?

   B. Uncertain outcome. Is the outcome of reaching the goal, uncertain?

      1. Does the activity have a variable difficulty level? For example, does the interface have successive layers of complexity?

      2. Does the activity have multiple level goals? For example, does the interface include score-keeping?

II. Fantasy

   A. Does the interface embody emotionally appealling fantasies?

   B. Does the interface embody metaphors with physical or other systems that the user already understands?

III. Curiosity

   A. Does the activity provide an optimal level of informational complexity?

      1. Does the interface use audio and visual effects: (a) as decoration, (b) to enhance fantasy, and (c) as a representation system?

      2. Does the interface use randomness in a way that adds variety without making tools unreliable?

      3. Does the interface use humor appropriately?

   B. Does the interface capitalize on the user's desire to have "well-formed" knowledge structures? Does it introduce new information when users see that their existing knowledge is (1) incomplete, (2) inconsistent, or (2) unparsimonious?

Table 1 Heuristics for Designing Enjoyable User Interfaces (From Malone, p.65) [117]

BIBLIOGRAPHY

These references are presented in six sections. The first section presents works of general interest. The second section addresses cognitive theory. The third section covers adult learning. The fourth section presents material having specific implications for computer assisted learning. The fifth section presents the research relating to the evaluation of CAL. The final section presents the literature pertaining to the design of ergonomically appropriate software.

I. RENEWAL INTEREST

1. Brahan, J.W. (1984) CAL Technology: "Decade past, Decade Present" Computers and Education, 8 (4), 323-333. Paper presented at the 4th Canadian Symposium on Instructional Technology, October, 1983.

   This paper reviews progress of computer-assisted learning technology to date with particular focus on National Research Council of Canada Computer Assisted Learning Project, and projects some computer-assisted learning developments to be expect during the rest of the 1980. (MRR)

2. Clark, R.E. (1984) "Learning from Computers: Theoretical Problems". Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA, April.

   Questions the expectation that computers will contribute any unique effects to learning.

3. Hofstetter, F.T. (1985) "Eighth Annual Peter Dean Lecture: Perspectives on a Decade of Computer-Based Instruction, 1974-1984." Journal of Computer Based Instruction, 12 (1), 1-7.

   This analysis of trends in computer-based instruction (CBI) during the past decade briefly describes evaluation criteria from 1974 and discusses changes in attitudes toward CBI (costs, instructional effectiveness); system selection criteria (graphics, input devices, quantity and quality of software); the CBI marketplace (including transportability of software); and future trends.

4. Montague, W.E. and Wulfeck, W.H. (1983) Computer-Based Instruction: Will it Improve Instructional Quality? San Diego, CA: Navy Personnel Research and Development Center.

Explains why, although the potential for improvement in instructional quality exists, progress will not be rapid or revolutionary.

5. Reynolds, A. (1983) "An introduction to computer-based learning". Training and Development Journal, 37 (5), 34-38, May.

   Defines computer-based learning terminology including modes of CAI and CMI.

6. Rogers, D.F., and Smith, P.R., (Eds.) (1983) "Computers and education". Selected proceedings from the Computer-Assisted Learning '83 Symposium. Bristol, England, April.

   Six papers on future developments in computer-assisted learning.

7. Streibel, M.J. (1983) Proceedings of the 2nd Annual Penn State Microcomputer Information Exchange Conference, University Park, PA, March.

   This collection of 17 conference presentations includes (1) "Project LOGO: A Study in Cognitive Enhancement Using Microcomputers," Henry Dobson; (2) "Tender Loving Card for Your Terrific Little Computer (TLC for your TLC), " Carol Dwyer and Karl Kelly; (3) "Teaching Micro-Literacy to Kids," Robert Gillingham; (5) "Teaching Music with the Apple II Microcomputer," William Higgins; (6) "The Design of a Microcomputer Data Base for Educators," Carol Jean Howard, Ronald Aitken, and Timothy Robinson; (7) "A Computer Programming Curriculum for High School (I, II, III)", Newton Kulp; (8) "Microcomputers in Engineering Graphics," William H. Park; (9) "Computer Camps for Children and Adults in America," Joan Parrett; (10) "Parallel Microprocessors; Mainframe Power for Micro Prices," Douglas J. Parsons; (11) "Microcomputer Appalications for Laboratory Sciences," Thomas Sandusky and Jeffrey D. Charney; (12) "Computer-Managed Instruction: Will I Control It or Will It Control Me?," Carol Scheftic; (13) "Computer Courseware for the Deaf and Learning Disabled: What's Being Done?," Casey Stone and Kathleen Smith; (14) "Microcomputer Anxiety," John Tongue; (15) "Computer Literacy for Professionals," Leslie E. Vance; (16) "Staff Development for Computer Literacy -- A Model Way?," James P. West; and (17) "The Unexpected Treasury: Developing Problem Solving Skills through Interactive Fantasy," J. Alan Whiteside. The Conference agenda is included.

II. COGNITIVE THEORY

8. Allen, B.S. and Merrill, D.M. (1985) "Systems Assigned Strategies and CBI." Journal of Educational Computing Research, 1 (1), 3-21.

   Presents a theoretical framework for designing computer-based systems which guide students in learning strategy selection; compares theories for determining when system-assigned strategies will promote knowledge and skill acquisitions; reviews relationship between learning and instructional strategies; and outlines potential applications of system-assigned learning strategies in computer-based instructional system design.

9. Allen, R.B. (1982) "Cognitive factors in human interaction with computers." in Badre, A. and Shneiderman, B. Directions in Human Computer Interaction. Norwood, NJ: Ablex.

   Examines experimental results, models, and research strategies relevant to cognitive processes in user interfaces.

10. Badre, A. and Shneiderman, B. (1979) Directions in Human/Computer Interaction. Norwood, NJ: Ablex.

    A collection of papers by twenty researchers in the general area of interactive system design and human information processing.

11. Biederman, I. (1976) "On processing information from a glance at a scene: some implications for a syntax and semantics of visual processing." In S. Treu (Ed.) User-Oriented Design of Interactive Graphics Systems. New York: ACM.

    Includes a discussion of the perception of photographs.

12. Bouma, H. (1980) "Visual reading processes and the quality of text displays." In E. Grandjean and E. Vigilani (Eds.) Ergonomic Aspects of Visual Display Terminals. London: Taylor and Francis.

    Discusses the relevance of legibility of text in visual displays.

13. Broadbent, D.E. and Broadbent, M.H.P. (1978) "The allocation of descriptor terms by individuals in a simulated retrieval system." Ergonomics, 21, 243-354.

    Cites findings which support hierarchical arrangements of information for certain individuals.

14. Brosey, M. and Schneiderman, B. (1978) "Two experimental comparisons of relational and hierarchical data-base models." *International Journal of Man-Machine Studies*, 10, 625-637.

    Cites findigns which support hierarchical arrangement of information for certain types of material.

15. Coke, E.V. and Koether, M.E. (1981) "Effects of display context on memory for attributive information." Paper presented at the meeting of the American Educational Research Association, Los Angeles.

    Spatial cues and typography are discussed with relevance to processing visual displays.

16. Connolly, D.W. (1979) Voice data entry in air traffic control. *FAA-NA-79-20*.

    Describes the use of a limited speech recognition system for data input by air traffic controllers.

17. Cooley, M.J.E. (1979) "Some social effects of computerism." *Infotech State of the Art Review*: Man/Computer Interaction. Maidenhead, U.K.: Infotech, 55-70.

    Discusses computer users' motivation, fears, and social pressures.

18. Costanzo, W. (1985) "Language, thinking and the culture of computers." *Language Arts*, 62 (5), 516-23, September.

    Discusses the logical and psychological significance of video games, microcomputer prose adventures, and computer programming.

19. Ehrenreich, S. and Porcu, T.A. (1982) "Abbreviations for automated systems: Teaching operators the rules." In A. Badre and B. Shneiderman (Eds.), *Directions in Human Computer Interaction*. Norwood, NJ: Ablex.

    Guidelines for generating abbreviations are generated, based on the results of several experiments.

20. Engel, F.L. (1980) "Information selection from visual display units." In E. Grandjean and E. Vigilani (Eds.) *Ergonomic aspects of visual display terminals*. London: Taylor and Francis.

    Discusses the impact of color on the ease with which text is read.

21. Gernsbacker, MA. (1984) "Educating with computers: Insights from cognitive psychology and video games." Paper presented at the third annual conference on The Computer: Extension of the human mind, University of Oregon, August 1984. University of Oregon: Center for Advanced Technology in Education.

22. Hartley, J.R. (1985) "Some Psychological Aspects of Computer-Assisted Learning and Teaching." Programmed Learning and Educational Technology, 22 (2), 140-149, May.

Considers three aspects of computer assisted instruction (CAI), i.e., instructional program design, software tools needed for the realization and assimilation of CAI in the classroom; discusses developments in CAI; and outlines techniques of knowledge representation arising from artificial intelligence and their value for student modelling and CAI design. (MBR)

23. Hartman, F.R. (1961) Single and multiple channel communications: A review of research and a proposed model. Audio-Visual Communication Review, 9, 235-262.

Discusses the advantages of using two different input modalities.

24. Hirsch, R.S. (1981) "Procedures of the human factors center at San Jose." IBM Systems Journal, 21, 123-171.

Includes a discussion of research on visual processing.

25. Hollan, J.D. and Hutchins, E. (1981) "Applications of Artificial Intelligence and Cognitive Science to Navy Computer-Based Instruction." Paper presented at the National Security Industrial Association conference on Personnel Training Factors in Systems Effectiveness. San Diego, CA, May.

26. Hsia, H.J. (1977) "Redundancy: Is it the lost key to better communication?" Audiovisual Communication Review, 25, 63-85.

Discusses the use of multiple input channels.

27. Kahneman, D. (1973) Attention and Effort. Englewood Cliffs, NJ: Prentice Hall.

Theoretical discussion relevant to visual processing and graphic displays.

28. Kearsley, G. (1985) "Embedded training: The new look of computer-based instruction." Machine-Medicated Learning, 1 (3), 279-295.

Describes on line instruction which is an integral part of a product or system and encompasses help systems, simulations, and intelligent tutors. This embedded training is emerging across all corporate, industrial, and military CBI applications. Based on a learner driven, problem solving style of learning rather than a tutorial or didactic approach. Design and implementation implications are discussed.

29. Kelly, M.J. and Chapanis, A. (1977) "Limited vocabulary natural language dialogue." International Journal of Man-Machine Studies, 9, 479-501.

    Discusses the use of a restricted vocabulary in natural language interfaces.

30. Limb, J.O. (1981) Integration of media for office services. Office Automation Conference Digest, 353-355.

    Proposes the use of keyboard and speech input for different purposes in text editors.

31. Malhotra, A. (1975) "Design criteria for a knowledge-based English language system for management: An experimental anlaysis" MIT/LCS/TR-146.

    Discusses the use of a restricted vocabulary in natural language interfaces.

32. McCombs, B.L. and Bruce, K.L. (1984) "Cognitive Style and Microcomputers: Instructional Management Potentials." Paper presented at the Annual Meeting of the association for Educational Communications and Technology, Dallas, Texas, January.

    Focuses on how microcomputer technology can be used to manage individualization that is based on student differences in cognitive style. Generalized approaches to individualization and the management of individual differences in cognitive style variables are discussed. Benefits from the use of computers for the management of this type of individualization and the requirements for management with microcomputers are presented. A discussio of practical issues and implications to be considered in an implementation of this approach concludes the paper. Twenty-five references are listed.

33. Michaelis, P.R., and Wiggins, R.H. (1982) "A human factors engineer's introduction to speech synthesizers." In A.N. Badre and B. Shneiderman, Directions in Human/Computer Interaction. Norwood, NJ: Ablex.

    Discusses issues in speech synthesis.

34. Miller, G.A. (1956) "The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63, 81-97.

    Discusses a model for short-term memory.

35. Munro, A. and Towne, D.M. (1979) *Research on self-directed learning to meet job performance requirements*. Los Angeles, CA: Behavioral Technology Labs, University of Southern California, February.

    Over a two-year period, research was conducted primarily in two areas of cognitive strategies for on-the-job training (OJT). The first area was the development and testing of a computer-based training system to improve selectivity in text processing in order to improve performance during OJT. The second area was exploration of text-type effects on learning from text. Preliminary results from this research suggest that learning from text may be measurably improved through the application of text processing techniques appropriate to the type of text being read.

36. Newell A. and Simon, H. (1972) *Human Problem Solving*. Englewood Cliffs, NJ: Prentice-Hall.

    The authors postulate a model of cognitive processing for problem solving.

37. Nickerson, R.S. (1984) *Research on the training of higher cognitive learning and thinking skills*. Final Report for the National Institute of Education. Cambridge, MA: Bolt, Beranek and Newman, Inc., January.

    The technical reports summarized in this paper were prepared as part of a project designed to determine what is known about the teaching of cognitive skills for further research. Topics discussed in the 22 reports include the following: (1) teaching thinking; (2) Aristotle's logic; (3) a conceptual framework for the teaching of thinking skills; (4) a theory of plausible reasoning; (5) structure mapping; (6) counting, computing, and the representation of numbers; (7) computer programming as a vehicle for teaching thinking; (8) problem theory; (9) the teaching of informal reasoning; (10) the nature of intelligence; (11) microcomputers in education; (12) understanding; (13) the teaching of learning strategies; (14) retrieval inhibition for part-list cuing; (15) teaching study strategies; (16) inquiry dialogue on the nature of lenses; (17) analogical development and the novice expert shift; (18) memory search of semantic categories following exposure to category instances; and (19) approaches to training information processing and problem solving skills.

38. Park, O. (1984) "Empirically Based Procedures for Designing a Response- Sensitive Sequence in Computer-based instruction: An example from concept teaching strategies. "Journal of Computer-Based Instruction", 11 (1), 14-18, Winter.

Describes the theoretical backgrounds and emirical findings of three experimental studies in which computer-based response-sensitive strategies were investigated using concept learning tasks. The strategy applied focused on discrimination learning, generalization learning, and classification skill developmen in concept learning. A general procedure for designing a response-sensitive sequencing strategy is proposed.

39. Pisoni, D.D., and Hunnicut, S. (1980) "Perceptual evaluation of MIT talk: The MIT unrestricted text-to-speech system." Proceedings of the International Conference on Acoustics, Speech, and Signal Processing, Denver, 572-575.

A study of the comprehensibility of synthesized speech in comparison to natural human speech.

40. Rabbitt, P.M.A. (1979) "Current paradigms and models in human information processing." In V. Hamilton & D. Warburton (Eds.) Human Stress and Cognition: An Information Processing Approach. Chinchester, U.K.: Wiley.

Discusses the effect of various stressors on cognitive processing.

41. Reisner, P. (1977) "Use of psychological experimentation as an aid to development of a query language." IEEE Transactions on Software Engineering, SE-3, 218-229.

Proposes a model of cognitive functioning for users of SQUARE and SEQUEL, two database access languages.

42. Salisbury, D.F. (1984) "Cognitive psychology and its implifications for designing drill and practice for computers." Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA, April 23-27.

This paper summarizes research in modern cognitive theory that relates to the role of computer drill and practice programs in learning and describes a prototype program that exemplifies recommended characteristics. Focus is on four major issues that are relevant to the design and optimization of computer drills: interference, spaced practice, spaced review, and capacity of short-term memory. Implications for the design of computer drills are suggested, including the need to: (1) present similar items in close proximity to ech other; (2) emphasize differences between similar items; (3) provide a mechanism to keep track of the items that a particular learner was working on during the last session; (4) provide a mechanism for reviewing items previously learned, based on the amount of time since the learner last responded to each item; (5) utilize increasing ratio-review; (6) present only a few items of information to the learner at once; and (7) combine meaningful stimuli into a single stimulus as chunking occurs. Some areas for future research are suggested.

43. Sheridan, T.B. (1980) "Computer control and human alienation." *Technology Review*, 83, 60-73.

    Discusses computer users' motivation, fears, and social pressures.

44. Simon, H.A. (1974) "How big is a chunk?" *Science*, 183, 482-488.

    Discusses models of short-term memory.

45. Thomas, J.C. (1976) "Quantifiers and question-making" *IBM RC 5866*.

    Discusses the approaches taken by individuals to tasks requiring the use of logic.

46. Thomas. J.C. (1978) "A design interpretation of natural English with applications to man-computer interaction." *International Journal of Man-Machine Studies*, 10, 651-668.

47. Thomas, J.C. and Carroll, J.M. (1981) "Human factors in communication." *IBM System Journal*, 20, 237-263.

    Discusses the use of schemas for command terms.

48. Thomas, J.C. and Gould, J.D. (1975) "A psychological study of Query-by- Example." *Proceedings of the National Computer Conference*, Anaheim, 439-445.

    Discusses the advantages of providing an explicit structure for the user to complete, in developing queries to a database.

49. Treisman A.M. and Davies A. (1973) "Divided attention to ear and eye." In S. Kornblum (Ed.) *Attention and Performance IV*. New York: Academic Press.

    Theoretical discussion relevant to the processing of graphics displays.

50. Wilson, B.G. (1985) "Tying it all together: Synthesizing Strategies for Computer-Based Instruction." Paper presented at the Annual Convention of the Association for Educational Communications and Technology, Anaheim, CA. January 17-23.

Computer-based instruction (CBI) is composed of individual frames viewed one at a time. Compared to a typical textbook, CBI restrict the adult learner's capacity to access information from different parts of the lesson and to view complex presentations.

51. Wright, P. (1977) "Presenting technical information: A survey of research findings." Instructional Science, 6, 93-134.

Reviews studies relevant to the cognitive processing of information on visual display terminals. Designers of CBI must compensate for these limitations by making a concerted effort to synthesize or tie together content parts, resulting in a coherent, stable cognitive structure in the learner's mind. Synthesizing strategies include: (1) using hard copy adjunct aids such as diagrams, figures, and content outlines; (2) implementing learner control features such as the menu and HELP options; (3) using graphic synthesizers such as lesson maps, diagrams, and other figures to periodically orient the learner toward the content structure; (4) using animation, graphics, sound, and timing to highlight structurally central content parts; (5) using verbal synthesizers such as analogies, stories, and advance organizers to relate content to familiar experience; and (6) providing integrated practice and other opportunities allowing the application of multiple skills to complex problems. This report concludes by relating research on CBI strategies to a framework for instructional science and discussions potential research questions.

III. ADULT LEARNING

52. Baltes, Paul B. and Schaie, K.W. (1974) "Aging and I.Q.: The myth of the twilight years." Psychology Today, 35-40, March.

    Reports on a study which disproves the previous belief in general intellectual decline.

53. Blum, J.E. and Jarvik, L.F. (1974) "Intellectual Performance of Octogenarians as a Function of Educational Initial Ability." Human Development, 17, 364-375.

    Reports on the association between educational achievement level and intellectual functioning.

54. Driskell, James E.; Dwyer, Daniel J. (1984) "Microcomputer Videogame Based Training." Educational Technology, 24 (2), 11-17, February.

    Examines advantages of using videogame format for training, including practicality, relatively inexpensive hardware, ability to use multi-purpose software modules, motivational advantages of increased student interest and instructional effectiveness, and instruction features such as teh adaptive interactive nature of videogames. An example of a videogame for military training is included.

55. Garrison, R. (1982) "Microcomputer and CAL in Adult Education." Lifelong Learning: The Adult Years, 5 (10), 22-23, June.

    Computer assisted learning has the capability to cope with the diverse needs and characteristics of the adult learner, to provide alternative means of reaching goals, to provide flexibility in pacing learning, and to provide for independent and self-directed learning. (SK)

56. Guilford, J.P. (1971) "Development of a theory." In R.A. Weisgerber (Ed.), Perspectives in Individualized Learning Itasca, IL: F.E. Peacock.

    Proposes a model applicable to adult learning.

57. Hamada - Alder, R. and White, M.A. (1982) Differences Between Children and Adults in Learning BASIC on Microcomputers. New York: Columbia University Teachers College.

    Do children and adults who are novices in their use of microcomputers differ in their approaches when learning a computer language? Ten fourth and fifth-grade students and 10 graduate students were observed learning the language BASIC on microcomputers. All sessions were tape recorded and verbalizations subsequently coded. Verbalizations, the number of computer operations executed, and the percentage of responses which were correct were compared for the two groups. The pattern of verbalizations was strikingly similar for children and adults. Monitoring and checking statements accounted for almost half of total verbal output, and questions to the examiner accounted for one quarter. Adults, more often than children, expressed negative comments about the computer. Although computer output for adults was greater than for children, there was no significant difference in the percentage of correct responses for the two groups. Possible explanations for these performance similarities and for the potential of the computer as an equalizer between young and old are discussed. (Author)

58. Karplus, R., et al. (1975) "Proportinal Reasoning and Control of Variables in seven countries." AESOP Report ID-25, Berkely, CA: Lawrence Hall of Science.

This research report suggests that experience is the first stage of the learning cycle.

59. Knox, A.B.; Grotelueschen, A.; and Sjogren, D.D. (1968) "Adult Intelligence and Learning Ability." Adult Education, 18 (3), 188-196.

A study of adult learners involving the factor of recent participation in a learning activity.

60. Knox, A.B. and Sjogren, D.D. (1965) "Research on Adult Learning" Adult Education, 15 (3), 133-137.

Reports on a major study of adults age 18 through 75.

61. Long, H.B. (1983) Adult Learning: Research and Practice. New York, Cambridge.

Describes current research in adult education and relates findings to the field in general.

62. Long, H.B. (1971) Are They Ever Too Old to Learn? Englewood Cliffs, NJ: Prentice-Hall.

Discusses social, physiological and personality factors for consideration in models of adult learning.

63. Monge, R.H. and Gardner, E.F. (1972) "A Program of Research in Adult Differences in Cognitive Performance and Learning: Backgrounds for Adult Education and Vocational Retraining." Syracuse University, Project No. 6, 1983. Grant No. OEG-1-706193-014a. Final Report.

Final report of a study in which the authors developed and administered tests which were designed to discern differential age trends among adults.

64. Montague, W.E. and Wulfeck, W.H. (1984) "Computer-Based Instruction: Will It Improve Instructional Quality?" Second Annual Air Force Conference on Technology in Training and Education, March.

Discusses the value of computer-based instruction in general.

65. Neher, W.R. and Hauser, L. (1982) "How Computers Can Help Adults Overcome the Fear of Learning." Training. 19 (2), 48-50, February.

Elements of the ideal match betwen adult learning and the computer are discussed: (1) autonomy, (2) utility, (3) integration, and (4) security.

66. Office of Education Research. (1981) Proceedings of the 22nd Annual Adult Education Research Conference. Dekalb: Northern Illinois University.

These proceedings contain 40 presentation papers, four alternate papers, and seven synopsis from the Twenty-Second Adult Education Research Conference. The 44 papers report on research, research problems, and research possibilities, including comparison of student performance in two curricular approaches, trust in small groups, overcoming culture-specific limitations on interviewing, evaluation model for nontraditional master's degree programs, continuing professional education and improved professional practice, motivational orientations and participant satisfaction with instructional environment, determining competent performance, disciplinary-interdisciplinary continuum of university continuing education noncredity programming, brain lateralization in adult learning, developing an evaluation usage model, employee assistance program, laboratory adult education, relationship between creative responses and self-esteem, importance of community needs, taxonomic framework for adult education practices, second language learning, andrasosical counseling techniques, teacher effectiveness, roles of continuing education program planners, learning strategies, and cognitive and affective outcomes of computer-assisted instruction. Focuses of the synopsis are alternate approaches to research on professional performance and related learning activities; reasons for participation in continuing professional education; naturalistic inquiry methodologies appropriate to adult learning research, doing philosophical research in adult education, early approaches to worker's education, contributions of research to academic program reviews, and literature as data source in research. (YLB).

67. Snow, Richard E. (1979) "Aptitude, Learner Control, and Adaptive Instruction". Paper presented at the Annual meeting of the American Eductional Research Association, San Francisco, CA, April.

Discusses the interation between aptitude and learner control in computer-based instruction.

68. Tennyson, Robert D, and Tennyson, C.L. (1977) "Computer Bsed Adaptive Instructional Strategies for the Improvement of Performance and Reduction of Time". Paper presented at the Annual meeting of the American Educational Research Association, New York, April.

Describes strategies for adaptive learning.

IV COMPUTER ASSISTED LEARNING

69. Abdulla, A.M. et. al. (1984) The use of natural language entry and laser videodisc technology in CAI. Journal of Medical Education, 59 (9), 739-45, September.

    The use of an authoring system is described that incorporates student interaction with the computer by natural language entry at the keyboard and the use of the microcomputer to direct a random-access laser videodisc player.

70. Allen, B.S. and Merrill, M.D. System-assigned strategies and CBI. (1985) Journal of Educational Computing Research. 1 (1), 3-21.

    Presents a theoretical framework for designing computer-based systems that guide students in learning strategy selection; compares theories for determining when system-assigned strategies will promote knowledge and skill acquisitions; reviews the relationship between learning and instructional strategies; and outlines potential applications of system-assigned learning strategies in computer-based instructional system design. (31 references)

71. Balajthy, E. (1985) "Artificial intelligence and the teaching of reading and writing by computers." Journal of Reading, 29 (1), 23-32, October.

    Discusses how computers can "converse" with students for teaching purposes, demonstrates how these interactions are becoming more complex, and explains how the computer's role is becoming more "human" in giving intelligent responses to students.

72. Barker, P.G. (1982) "some experiments in man-machine interaction relevant to computer assisted instruction." British Journal of Educational Technology, 13 (1), 65-75, January.

    Briefly describes some experiments in human-machine interaction in the context of its relevance to multimedia audiovisual instruction, with emphasis on the use of microcomputer systems augmented with slides or audio cassettes. Fifteen references are listed.

73. Bork, A. (1981) Learning with Computers. Bedford, MA: Digital Equipment Corporation.

    Focuses on the use of the computer as a learnign device, with chapters on the role of graphics, applications of the computer in science education, and the CBI development process.

74. Card, S.K., Moran, T.P., and Newell, A. (1983) The Psychology of Human- Computer Interaction. Hillsdale, NJ: Lawrence Erlbaum Associates.

    Focuses on the task domain of text-editing and similar types of highly interactive systems.

75. Copeland, P. (1983) "An interactive video system for education and training." British Journal of Educational Technology, 14 (1), 59-65, January.

    Describes and interactive video teaching system (CAVIS) which mixes videocassette pictures, text, and videotex diagrams and presents via single television screen with sound. The development of CAVIS, related research, teacher-learner interaction, how CAVIS works, creating courseware, equipment compatibility, and evaluating trainee and courseware performance are highlighted. Nine references are cited.

76. DeBloois, M.L., (Ed.) (1982) Videodisc/Microcomputer Courseware Design. Englewood, NJ: Educational Technology Publications.

    A primer on the instructional design process involved in creating interactive courseware.

77. Goldes, H. (1984) "User problems in interactive environments." British Journal of Educational Technology, 15 (3), 161-75, October.

    Describes design requirements for user-friendly computer software.

78. Goos, G. and Hartmanis, J. (Eds.) (1984) Lecture Notes in Computer Science: Readings on Cognitive Ergonomics-Ming and Computers. Berlin: Springer-Verlag.

    Proceedings of the second European Conference, Gmunden, Austria, September, 1984.

79. Henderson, C. (1984) "Inviting Success in Computer-Assisted Instruction". Paper presented at the 68th Annual Meeting of the American Educational Research Association, New Orleans, LA, April.

    Presents guidelines for designing educational software so as to maximize humanistic use of this medium.

80. Jonassen, D.H. (1985) Interactive lesson designs: A taxonomy. Educational Technology, 25 (6), 7-17, June.

Proposes a taxonomy which describes interactivity and adaption outside the context of any particular medium. Designed to facilitate the instructional design and media selection processes, this taxonomy is represented as a cube whose axes represent interactivity and internal and external adaptation levels. Levels of interactivity and adaptation are discussed.

81. Kearsley, G. (1985) Training for Tomorrow. Reading, MA: Addison-Wesley.

An overview of the changes taking place within the workplace with a focus on training requirements met through distributed learning.

82. Laird, D. and House, R. (1984) Interactive Classroom Instruction. Glenview, IL: Scott, Foresman and Co..

Discusses the concept of interactivity in detail.

83. Langley, P. and Carbonnel, J.G. (1984) "Approaches to machine learning" Journal of the American Society for Information Science. 35 (5), 306-16, September.

Reviews approaches to machine learning (development of techniques to automate acquisition of new information, skills, and ways of organizing existing information) in symbolic domains. Four categorical tasks addressed in machine learning literature are examined: learning from examples, learning search heuristics, learning by observation, and language acquisition.
(36 references)

84. Mahoney, F.X. and Lyday, N.L. (1984) Design is what counts in computer- based training. Training and Development Journal. 38 (7), 40-41, July.

Four key areas in the design of computer-based training are transfer of training, interactivity, development of problem-solving skills, and stimulation of learner interest.

85. Salvendy, G. (Ed.) (1984) Human-Computer Interaction. Amsterdam: Elsevier Press.

Proceedings of the first U.S.A.-Japan Conference on Human-Computer Interaction, Honolulu, 1984.

86. Van Matre, N., et. al. (1984) Computer Managed instruction in the Navy: A comparison of two student/instructor ratios in CMI learning centers. San Diego, CA: Navy Personnel Research and Development Center, February.

V. EVALUATION OF CAL

87. Carroll, J.M. (1982) "The Adventure of Getting to Know a Computer". IEEE-82, 49-58, November.

    A number of problems are faced by novice computer users which can be overcome with effective courseware design.

88. Dennis, J.R., Kansky, R.J. (1984) Instructional Computing. Scott, Foresman & Co., New Jersey.

    A history of the computer in the classroom is given along with a checklist for evaluating CAL software.

89. Gastkemper, F.H.D. (1984) "The integrated Use of Computer Assisted Instruction (CAI) and Videodisk (VLP) for Observation Training". Computer Education, 8 (1), 219-224.

    Integration of the computer with vide was perceived favourably by students of psychology for observation training. Advantages to this use include immediate and frequent feedback, maintaining attention, and faster learning.

90. Goldes, H. (1984) "Courseware Basics". PC Mag, 305-307, August.

    Courseware for computer should be designed along the conventional vein, giving as much control to the user as possible, and as much directiona as possible.

91. Gomez-Mejia, L.R., Balkin, D.B. (1980) "Can internal management training programs narrow the male-female gap in managerial skills?" Personnel Administrator, 25 (5), 77-83, May.

    Mixing training tools was found to be more effective in developing managerial skills in women than men when these skills are less developed than those of men.

92. Hathaway, M.D (1984) "Variables of Computer Screen Display and How They Affect Learning". Educational Technology, 7-11, January.

    Recommended text density, text size, scrolling speed, use of upper and lower case lettering, graphics, and frequent rest periods are proposed to enhance learning.

93. Horn, R.E., Nicol, E.H., Kleinman, J.C., et. al. (1969) Information Mapping. Air Force Electronic Systems Division, Information Resources, Inc., Cambridge, Mass.

    Information mapping is used to develop a system that will facilitate individualized information presentation.

94. Kearsley, G.P., Hillelsohn, M.J. (1982) "Human Factors Considerations for Computer-Based Training". Journal of Computer-Based Instruction, 8 (4), 74-84, May.

Human factors affecting computer-based training relate to human/ computer interfaces, training administration, management, instructional design and development, testing and evaluation, motivation, and hardware.

95. Ketner, W.D. (1981) "The Videodisc/Microprocessor For Training". Training and Development Journal, 35 (5), 151-153, May.

The integration of computer and video provides a useful mechanism for reinforcing and assisting recall of technical procedure training.

96. Kidd, M.E., Holmes, G. (1984) "CAL Evaluation: A Cautionary Word". Computer Education, 8 (1), 77-84.

The use of statistical techniques as measures of CAL effectiveness or not necessarily the best evaluation yardstick. Personal observations, experience and intuitions are often good guides and should not be discounted.

97. Koenig, J., Lee, M. (1982) Authoring Computer-Aided Learning Materials: Some Guidelines. Interactive Image Technologies Inc. November, Toronto, Ontario.

Various characteristics of good courseware development and use are presented.

98. Kulik, J.A. (1983) "Synthesis of Research on Computer-Based Instruction". Educational Leadership, 41 (1), 19-21.

A summary of research, known as meta-analysis, into the effects and effectiveness of CAL is presented.

99. McConnell, V. (1979) "Implementing a New System Through a User Training Program". Retail Control, 48 (4), 2-27.

The elements for effective implementation of a system for end user is described.

100. Miller, G.A. (1956) "The magical number seven plus or minus two: some limits on our capacity for processing information". The Psychology Review, 63 (2), 52-60, March.

A number of experiments are cited which indicates the inability of human to handle more than about seven plus or minus two chunks of information at a time.

101. Montague, W.E. Wulfeck, II, W.H., Ellis, J.A. (1983) "Quality CBI Depends on Quality Instructional Design and Quality Implementation". *Journal of Computer-Based Instruction*, 10 (3&4), 90-93.

Various reasons are suggested for problems associated with computer-based instruction, the solutions to which involve better development aids and management of implementation.

102. Morrison, J.E., Witmer, B.G. (1983) "A Comparative Evaluation of Computer-Based and Print-Based Job Performance Aids". *Journal of Computer-Based Instruction*, 10 (3&4), 73-75.

A preference for the computer-based job aid was found among soldiers, however, comparable performance gains were not exhibited.

103. Reid, S. (1982) *Memo: Radio Shack - Courseware Standards*. Holt, Rinehart & Winston of Canada, Ltd., November 24.

Characteristics of good screen design and a checklist for evaluating CAL courseware are discussed.

104. Ridgway, J., et. al. (1984) "Investigating CAL?" *Computer Education*, 8 (1), 85-92.

Teachers were given the opportunity to use a variety of CAL programs in their course and to evaluate them. The finding was that these programs were readily accepted fi they fit in with existing curriculum, and that a more open teaching style emerged.

105. ____________________ . (1984) "Conclusions from Catastrophes". *Computer Education*, 8 (1), 93-100.

Impediments to successful CAL are noted as unreliable hardware and software, inappropriate classroom design, unfamiliarity with the software and its operation, inadequate integration into curriculum.

106. Tait, K. (1984) "The Building of a Computer-Based Teaching System". *Computer Education*, 8 (1), 15-19.

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107. Tait, K., Hughes, I.E. (1984) "Some Experience in Using a Computer-Based Learning System as an Aid to Self-Teaching and Self-Assessment". Computer Education, 8 (3), 271-278.

> The MCQ system is discussed in relation to an application for pharmacology. The system is favourably perceived and results indicate some enhancement to learning.

108. Vazquez-Abad, J, Larose, R. (1984) "Computers, Adaptive Teaching and Operational Learning Systems". Computer Education, 8 (1), 27-29.

> The system, Operational Learning Systems, is presented as an approach to individualized instruction.

109. Watson, D.M. (1984) "The Role of CAL in Decision-Making in the Humanities". Computer Education, 8 (1), 31-34.

> The potential for interdisciplinary use of CAL is demonstrated through the presentation of a variety of programs and what they are designed to do.

110. Whiting, J. (1984) "Cognitive and Student Assessment sof a CAL Package Designed for Mastery Learning". Computer Education, 8 (1), 59-67.

> CAL instruction was found to be effective in promoting learning.

111. Yeaman, A.R.J. (1984) "Put Your Computers in the Most Efficient Environment". Instructional Innovator, 29 (1), 32, Janury.

> Ergonomic factors of screen display and position, furniture, and fatigue and stress are important considerations in computer usage.

VI. THE ERGONOMICS OF SOFTWARE

112. Allen, R.B., (1982) Cognitive factors in human interaction with computers, p. 1-26 in Badre, A., Shneiderman, B. (Eds.) (1982). Directions in human-computer interaction. Ablex, Norwood, New Jersey.

This article examines experimental results, models, and research strategies relevant to cognitive processes in user interfaces.

113. Foley, J.D., Wallace, V.L. (1974). The art of natural graphic man-machine conversation. Proceedings of the IEEE, 62, 4, 462-471.

This article presents guiding rules and principles for designing interactive graphic systems whose aim is good symbiosis between man and machine.

114. Heckel, P. (1982). The elements of friendly software design. Warner: New York.

This small book presents numerous principles, guidelines, rules, or criteria for designing friendly interactive systems.

115. Hutchins, E., Hollan, J.D., Norman, D.A. (1985). Direct manipulation interfaces. Center for Human Information Processing, University of California, San Diego, La Jola, CA

This paper presents the nature, form, and history of direct manipulation user interfaces.

116. Malone, T.W. (1981). What makes things fun to learn? A study of an intrinsically motivating computer game. Paper presented at the American Educational Research Association Annual Meeting, April 13-17, Los Angeles, CA

This article examines two questions: (1) Why are computer games so captivating? and (2) How can the features that make computer games captivating be used to make learning - especially learning with computers -- interesting and enjoyable?

117. Malone, T.W. (1982). Heuristics for designing enjoyable user interfaces: lessons from computer games, p.63-68 in Proceedings of Human Factors in Computer Systems, March 15-17, Gaithersburg, Maryland.

This article addresses the same two questions as the precedent. It presents guidelines for designing enjoyable user interfaces.

118. Martin, J. (1973). Design of man-computer dialogues - Englewood - Cliffs, New Jersey: [Prentice-Hall]

This book is based on a course given at the IBM Systems Research Institute. It contains 32 chapters covering different aspects of human-computer dialogue.

119. Moran, T.P. (1981). The command language grammar: a representation for the user interface of interactive computer systems. International Journal of Man-Machine Studies, 15, 3-50.

This article introduces and discusses a specific grammatical structure - the Command Language Grammar - as a representational framework for describing the user interface aspects of interactive computer systems.

120. Robert, J.M. (1985). Learning by Exploration, 150-155, in Proceedings of the 2nd IFAC/IFIP/IFORS/IEA Conference, on "Analysis, Design, and Evaluation of Man-Machine Systems", September 10-12, Varese, Italy.

This article presents the strategies and cognitive processes used by people for exploring a personal computer, and the different problems that are encountered while doing so.

121. Robert, J.M. (1985) A formal method for designing the interface of interactive systems, 275-280, in Proceedings of the 2nd IFAC/IFIP/IFORS/IEA Conference on "Analysis, Design, and Evaluation of Man-Machine Systems", September 10-12, Varese, Italy

This article presents a formal method based on a systematic description for analyzing the interface of a system and making predictions of the user's difficulties and errors. Then the interface can be corrected and the system friendliness be improved.

122. Robert, J.M. (1986) An approach for verifying the consistency of user interfaces. Proceedings of the International Scientific Conference on "Work with Display Units", May 12-15, Stockholm, Sweden.

This article presents a systematic method for locating, describing, and classifying the inconsistencies of an interface if there are any.

123. Shneiderman, B. (1982) Software psychology. Human factors in computer and information systems. Winthrop, Cambridge, MA

This book reviews current trends and experimental results which have immediate application in software engineering and offers a model of human behavior which may be useful for further research.

124. Shneiderman, B. (1983) Direct manipulation: a step beyond programming languages. IEEE Computer, August

This article presents a review about direct manipulation user interfaces.

125. Shriffin, R.M., Dumais, S.T. (1981). The development of automation, 111-140, in Anderson, J.R. (Ed.) Cognitive skills and their acquisition. Erlbaum, Hillsdale, N.J.

This article explains how and why humans develop automatisms in their behaviors and cognitive processes.

126. Smith, D.C., Irby, C., Kimball, Verplank, B. (1982). Designing the STAR user interface. Byte, 7 (4), 242-282

This article presents the design principles of the STAR system. It shows how the STAR differs from other office computer systems and what makes its user interface a success.

127. Suwa, M., Scott, A.C., Shortcliffe, E.H. (1982). An approach to verifying the completeness and consistency in a rule-based expert system. The AI Magazine, 3, 16-21

This article describes a program for verifying that a set of rules in an expert system comprehensively spans the knowledge of a specialized domain.

128. Verplank, W.L. (1985) Graphics in Human - Computer Communications principles of graphical user-interface design. Xerox Palo Alto Research Center, Office Systems Division, California.

This article focuses on the need for good graphic design in user interfaces. The author relies on experience he acquired during the design process of the STAR system.

129. Young, R.M. (1981) The machine inside the machine: users' models of pocket calculator. International Journal of Man-Machine Studies, 15, 51-85.

This article addresses the question of mental model developed by the user of a device.

2. LITERATURE REVIEW: ERGONOMY OF COMPUTER WORKSTATIONS

2.1 Introduction

In this section we review the literature concerning ergonomic criteria for the design and evaluation of work with VDTs (Visual Display Terminals). This report is intended to serve as a guide to designers and as such, appears as a series of precise and detailed recommendations. It covers issues that contribute to the comfort, well-being, security, and efficiency of VDT operators.

In the preparation of this study we have examined a range of existing reviews of literature about work with VDTs mainly Cakir et al. [2] (1980), Grandjean & Vigliani [7] (1980), and IRSST [9] (1984). Other studies by Carroll [4] (1978), Davis & Swezey [5] (1983), Garelly & Montmayeul [6] (1980), IBM [8] (1984), and Pérusse [14] (1981) were also consulted for a more complete investigation. Finally the works of one of the co-authors (Robert [17] [18] 1982a, 1982b) were used because of their pertinence for this study. The results of these different reviews were compared and summarized, and the recommendations that seemed to be well accepted were extracted. These recommendations are presented here: we are quite confident that they represent the state-of-the-art of the knowledge on the ergonomy of computer work stations.

These recommendations cover the ergonomic requirements for the terminal, the workstation, the work environment, the organization of work and rest periods, and the training and information needs. Their implementation should proceed with some flexibility. Individual users may give preference to other solutions because of specific task requirements, or work environment conditions, or anthropometric dimensions, or personal choice. It is thus necessary to understand the "why" and "how" of each recommendation.

Because of time constraints, methodological aspects of the research reviewed by the authors are not assessed. We have accepted prima facie the validity of their analyses and recommendations. For the same reason and because of the design orientation of this paper, we did not directly cover the health problems (e.g., ocular, visual, postural, muscular, or reproduction, etc.) that are often associated with VDTs. The reader interested in these problems should consult IRSST [9] (1984) for a recent and complete review. (See also the chapter on Standards and Norms).

Throughout this paper we stress the involvement of the people who are the most concerned with the work at VDT: the operators. They have an important place in the design and implementation of their workplace. They are aware of the problems they are having and often have the most immediate and intensive experience and understanding of the appropriate solutions.

In the next chapter we provide information on how various governments and non-governmental bodies have responded to the directions indicated by the research literature in the promulgation of standards and norms for VDT design and implementation.

2.2 Terminal

The legibility of the display and the "feel" and useability of the keyboard are the most important criteria by which the user judges the "quality" of VDTs and the merits of working with VDT-based systems. Particular attention should thus be given to the ergonomic requirements of the components of the VDT including the screen, the keyboard and so on.

2.2.1 Visual Display

The visual display is the means (often the only one) for checking the content and accuracy of the information which is entered via the keyboard. In that respect, it serves a vitally important control function in allowing the information to be searched in order to locate specific items of information or errors.

The display technologies that are available include cathode ray tubes (CRT), light emitting diode (LED), liquid crystal displays (LCD), and electroluminescent (EL) and plasma displays. Most of the following recommendations are concerned with CRTs that are the most commonly used devices. [2] [4] [5] [6] [7] [8] [9] [14] [17] [18][1]

1. The height of the screen should be adjustable (either directly or by means of a lever). The upper edge should be between 370 and 520 mm above the work surface, or at or below the height of the eyes.

2. The screen should be adjustable around its horizontal axis to be at right angle to the operator visual angle (5° forward and 20° backward) and to help eliminate reflections. If fixed, it should be roughly on a vertical plane to prevent reflections from the ceiling.

3. If the dot matrix is adopted as character generation method, the resolution should be 7 x 9 to ensure better legibility, i.e. to present a more natural image to the viewer (however, a matrix of 5 x 7 dots is acceptable). The individual dots should merge sufficiently well so as to produce a sharp and well defined image.

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[1] Consultant does not necessarily agree with all the recommendations

4. The display should be completely free of perceptible movement (i.e. "flicker"). The stabilization of the power supply, both as regards voltage and frequency, should be guaranteed. The refresh rate of the CRT should be 35 Hz if the persistence of the phosphore is high, 50 Hz if it is average, and at least 60 Hz if it is rather weak. Some authors say that displays are not flicker-free under about 50 Hz.

5. The number of raster lines within which each character matrix is formed should not be less than 10; this affects the degree of refinement of the character shapes.

6. The minimum character height should be between 16' and 20' of an arc (20' is preferable), i.e. 3.1 - 4.2 mm (a variation of 3.1-5 mm can be found in the literature). It should however exceed 20', i.e. 3.0 mm, for a viewing distance greater than 50 cm.

7. The character width (i.e. the width or cell within which each character image is formed) should be between 70% and 80% of the character height so as to maintain a mutual proportion in the visual appearance of each character (varies between 50% and 100% depending on the author).

8. The stroke width should be between 1/6 and 1/8, i.e. 12% - 17% of the character height to ensure the clarity of each character image.

9. Special attention needs to be given to the following characters because they are commonly confused in visual displays:

Mutual	One way
O and Q	C called G
T and Y	D called B
S and 5	H called M or N
I and L	J, T called I
X and K	K called R
1 and I	2 called Z
	B called R, S, or 8

10. Basic characters should be upright, not slanted.

11. For normal text, both upper and lower case characters should be used because they are generally easier to read than all upper case. This helps in the recognition of words as units rather than forcing character by character recognition.

12. Character spacing should not be less than about 20% of the character width, and should not exceed 50% of the character width to ensure good readability and to maintain the visual distinction between individual characters and words (there

13. The optimal space between two words is 66% of character height.

14. Generally speaking, interline spacing should not be less than 100% and not greater than 150% of the character height. Immediately adjoint ascenders and descenders should not overlap or intersect (A variation here of from 50% to 150%).

15. The screen size (or display capacity) should be sufficient for the job requirements. The nature of the job determines the amount of information to be displayed at one time. The most common CRT sizes for desk-top VDTs have a diagonal dimension of 30.5 to 38 cm. The display capacity of most text input and editing VDTs seldom exceeds 25 to 30 lines of text. The screen extremities should be avoided where possible (see Shannon & Stewart [19] 1984).

16. The proportions of the screen should correspond to the job requirements. Here again, only the job can help to define the shape of the screen that would be the most appropriate.

17. A scrolling facility might be provided to allow the user to jump backwards and forwards through a document. The task requirements will define the optimal time to recall parts of text and the type of scrolling to be adopted (1 line at a time, or 1 page, or a more continuous presentation).

18. A phosphore with a level of persistence such that the image does not smear when it is scrolled down, should be chosen.

19. Several authors recommend positive contrast, i.e. dark characters or image on a light background. However, this is often a matter of personal choice.

20. Windows can be used for displaying more information on a screen. The number of windows that can be presented at a time and the operations that can be done with them (e.g., open/close, move, resize, overlap, scroll within the window, etc.) can each be separately defined. (See Ramsey & Atwood [15] 1979 for recommendations about windowing vs scrolling).

21. The lay-out of the visual display should be organized and structured in a form which is suited to the task (e.g., its sequence) and to the frame of reference of the operator. Inappropriate display lay-outs waste time, can be confusing, and might cause errors. (See Miller & Thomas [12] 1977 for more information about the partitioning of the screen).

22. The sequence in which information is to be requested and entered into the display should be derived from the nature of the task.

23. Different displays engaged in the same task should be consistent as well as different modes of handling the same task and the requirements for subsequent stages in handling the same data.

Coding: For a comparison of different types of coding (of visual symbols), see Davis & Swezey [5] (1983), Martin [11] (1973), Van Cott & Kinkade [20] (1972) Williges & Williges [21] (1981)

24. Grouping and the use of blank spaces can provide structure in the display and aid in the recognition and identification of specific items of information.

25. Brightness: no more than 2 levels should be used, corresponding to normal and bold appearance, otherwise the levels could not be clearly distinguished.

26. Blinking:

- the optimum blink rate should be in the range of 3-5 Hz;
- no more than one blink rate should be used at a time (2 or more could confuse the appearance of the display);
- the blinking should stop when the source part has been located and is being attended to (otherwise blinking could be annoying for the operator).

27. Special symbols (Icons) should be easy to distinguish, i.e. differ from the ones which serve some purpose in the display, be distinct from one another to avoid the risk of interpretation error, and in the case of graphic displays, have a high level of association with the objects they represent.

28. Size: no more than 3 sizes should be used for "coding" purposes otherwise interpretation errors may become frequent. (Note that several other types of coding can be used in addition to those already cited: reverse-video, underlining, fonts, styles, colors, etc.)

29. The cursor should be:

- easy to locate at any random position in the display;
- easily tracked as it is moved through the display;
- should not interfere with the reading of the symbol that it marks;
- should not be so distracting as to impair the searching on the display for information unrelated to the cursor;
- should not be represented by a graphic technique or symbol that is used for some other purpose in the display;

- if it blinks (between 3-5 Hz is best), the operator should be able to control the blinking rate and suppress blinking to prevent annoyance. See Williges & Williges [21] (1981) for more information on cursor control.

30. The color of the characters could be white, green, yellow, orange. It is a matter of personal preference. It is often claimed that green is a suitable color for visual displays because the spectral sensitivity of the eyes is greatest in the green part of the spectrum, and hence less tiring. Provided that the luminances and luminance contrast of the display are sufficient to ensure good readability however, there is no evidence to suggest that any one colour (except red) is less tiring than any other.

31. Character luminance should be in the range of 80 and 160 cd/m^2 (the literature has variations between 20 and 200) and be operator adjustable. Character images should remain sharply defined at maximum character luminance.

32. The screen background luminance should be between 15 and 20 cd/m^2 (variation in the literature between 10 and 20) under the appropriate office lighting conditions, and be operator adjustable.

33. The luminance contrast between the characters and the screen background should be in the range of 8:1 to 10:1 (optimal), and be operator adjustable.

34. The contrast between the screen background and other items in the working field (e.g. documents) should be in the range of 1:3 to 1:5.

35. The operator should be able to independently adjust the luminance of the characters and the luminance of the screen background. These two adjustments must be made when the operator is sitting in front of the terminal.

36. The colour of the console should be neutral and matt (e.g., grey). Black or bright colours should be avoided.

Other Aspects:

37. The response time of the system should be constant and as short as possible. If not, the operator should be given an indication of waiting time (e.g., clock).

38. The operational status of the VDT should be made known to the operator at each moment (e.g., through a continuous light indicator).

39. The operator must be secured against electrical accident even when tampering with the VDT.

40. The electrical supply cables and other services to the VDT and workplace should be adequately secured and concealed.

2.2.2 Screen Filters

Screen filters are used to combat the problem of screen reflections and improve the visual quality of the display. However, they work at the expense of reduced character brightness and resolution, and should thus be approached with caution. There are several types of screen filters. Each type has its own advantages and disadvantages and the individual merits may vary from one application and environment to another. The following issues should be considered: [2] [9] [17] [18]

1. Before installing a screen filter, the following actions should be taken to eliminate reflections:
   - position the terminal in relation to sources of the reflections (e.g., windows, shiny objects);
   - if possible, remove shiny objects from the reflection field of the screen;
   - adjust the display screen level to the operator's height in order to minimize upward screen inclination;
   - adjust the lighting level of the room or workstation to the operator's convenience;
   - adjust the screen background luminance to the operator's convenience.
2. If there are still reflections on the screen, a screen filter should be installed. There are many types of filters which can be ranked as follows for use in normal office environments: thin-film or quarter wavelength layer, etching, polarisation filter anti-glare treatment, micromesh filters, polarisation filters (see Cakir et al. p. 84-92 [2] for a description).
3. Filters that make the screen completely dark and create excessive contrasts with the environment should be avoided as well as ones that excessively reduce character luminance and the contrast between the character and the screen background.
4. Screen filters should be regularly checked for transparency, good adherence to the screen, etc.

5. Operators should have the possibility of trying and comparing different screen filters and choosing the most appropriate one for their workstation.

6. The surface of the screen or screen filter should be regularly and carefully cleaned (to be free of dust, finger prints and pencil points). An appropriate rag and cleaning solution should be available in each work environment.

7. If a re-arrangement of the workstation and a screen filter do not suffice to eliminate screen reflections, side and top anti-reflection hoods could be added to the screen.

8. Under extremely unfavourable lighting conditions, screen filters may be combined with the use of a tube shield (tubular type of shield). However, this is an extreme measure because it tends to enforce a fixed, often unfavourable working posture. Care should be taken to prevent this problem.

2.2.3 Keyboard

The keyboard is the input device that is used the most in human-computer dialogues. Other pointing devices are the mouse, the joystick, the lightpen, the trackball, the touch screen, the tablet and electronic pen, and the voice (see Card et al. [3] 1978, Janet [10] 1980, Ritchie & Turner [16] 1975 for a comparison of the advantages and disadvantages of various input devices). The keyboard enables one to command the system, enter data, ask and answer questions, carry out critical operations, etc. Its characteristics affect directly the keying speed and accuracy of the operator and play a major role as far as the incidence of fatigue and other forms of discomfort among VDT operators is concerned. (See Alden et al. [1] 1972 for a review of the major issues in keyboard design). The following issues should be considered:[2] [5] [6] [8] [9] [14] [17] [18]

1. The keyboard should be detached from the display screen and joined to it by a flexible cable, long enough for the requirements of the user working style.

2. The profile angle of the keyboard should be between 5° and 15°. This angle is favourable for the position and motion of the hands and fingers: it minimizes their physiological loading and ensures good keying performance.

3. The keyboard should be as thin as possible: the distance from its base to the home row of keys should not exceed about 30 mm (a variation of 30 to 40 mm in the literature). This helps to reduce the postural loading on the user.

4. The keyboard width should not exceed a maximum of 420 mm.

5. The keyboard should be heavy enough to stay stable through unintentional movements of the operator.

6. There should be a minimum of 50 mm between the space bar (which should be at the bottom of the keyboard) and the keyboard's edge for resting the palms of the hands.

7. Keytops should be square rather than circular because this shape provides a bigger target area for a given spacing between key centres.

8. The keytop size should be between 12 and 15 mm; the inter-centre spacing should be between 18 and 20 mm (a variation of 16 and 20 mm); the distance between the 2 edges should be between 3 and 6 mm; and the distance between 2 rows should be between 1 and 4 mm.

9. Keytop surfaces should be concave to aid the accurate location of the user's finger (there is little systematic research on the practical significance of key shapes). The degree of concavity is important to keep specular reflections to a minimum.

10. Keytop surfaces should not be too roughened because this leads to accumulation of dust and grime which may in turn obscure the keys' legends and is also aesthetically and perhaps hygienically unpleasant.

11. Keys' legends should be moulded into the keytop to resist wear and abrasion.

12. There should be a good contrast between the keys' colour and the keys' inscription colour (e.g., light key with dark letters and numbers).

13. The keyboard's frame and keys should be of clear and neutral colour, and matt finished (black, white, or bright colours should be avoided). This minimizes reflection and provides a non-slip target.

14. The luminance ratio between the keyboard, the screen, and the documents should be less than 3:1 or 1:3.

15. The reflectance of the keyboard surface (not single key) should be between 0.40 and 0.60.

16. There must be an audible (click) and kinesthetic feedback from the keyboard. Feedback is important for accurate and rapid keying and self-detection of errors (typically 70% of all errors are self-detected.)

- the user should be able to control the level of the audible feedback for more comfort;
- the force required for key displacement should be between 0.25 and 1.5 N (others suggest between 25 and 150g);
- the key displacement (travel) should be between 0.8 and 4.8 mm (varies between 0.8 and 8 mm).

17. Legends should be uniform in size and as large as possible. They should not be smaller than the minimum acceptable character size on the screen, i.e. 3 mm, since ideally the distances eye-keyboard and eye-screen should be the same.

18. The QWERTY keyboard layout which has become the universal keyboard layout for typewriter and terminal keyboards should be adopted (see Noyes [13] 1983 for a review on the QWERTY keyboard).

19. The labels of function keys should be standard symbols where these exist (e.g., arrow symbols for cursor controls).

20. Cursor control keys should be arranged so as to correspond to cursor movement.

21. Abbreviation of function key labels must be meaningful, simple, and consistent in order to be easy to remember. In practice, very few users can remember more than a few such functions and it is difficult to imagine how meaningful abbreviations could be written into the appropriate keytops.

22. If necessary, a look-up list of function keys should be provided when the users feel it would be of value to them.

23. All keyboards used by the same operator should be similar and all the function key labels and symbols should correspond to the same functions on other keyboards. This helps to prevent adaptation difficulties and errors.

24. The keyboard should be provided with an n-key roll-over capability in order to store all the keystrokes that might be made in a burst and generate all the characters in the correct sequence. With no roll-over, the second keystroke is lost completely. This capability is mostly useful if data-entry is an important work component, and if users are fast typists.

25. If two or more keys are activated simultaneously, there should be a warning signal.

If function keys are being used:

26. The number and type of function keys should correspond to the requirements of the task, and their arrangement should correspond to the sequences with which the task is carried out.

27. The number of functions keys should be kept low so that the user can easily access them, otherwise they won't be used in practice. Remembering them and how they operate might require more effort than finding a longer way of doing the same thing.

28. The keyboard should have some means to prevent critical errors: either by chord keying (the required simultaneous depression of 2 or more keys), by double-pressing (the repeated action of a given key), or by sequential keystroking (the depression of 2 or more keys in a specific sequence). There is no direct evidence as to which of these 3 approaches to safeguarding is most appropriate.

29. All the critical command/function keys should be positioned separately from the more frequently used alphanumeric keys and less critical functions, or have other safeguards such as key lock, two handed chord operation, or a higher required key pressure.

30. Colour, shape, position, and distance are effective ways of aiding the user in locating the correct function keys. Furthermore, they give a structure to the keyboard which is functionally desirable and aesthetically pleasing. Groups of keys with different functions must be of different colours.

31. The keyboard should have an UNDO (or KILL or DELETE) key to allow the user to undo any inadvertent operation.

32. It should also allow the user to 'undelete' a killed item if it is later decided that the command was inappropriate.

33. The keyboard should have a facility to repeat certain characters or symbols continuously: either by having a separate repeat key which, when depressed, will repeat any other key instruction that is depressed at the same time, or by using typamatic keys which automatically repeat when depressed for more than a short period of time, typically half a second. For most applications, only a few characters (e.g., underline symbol) need to be regularly repeated so that the selective use of typamatic keys may be sufficient.

If substantial quantities of numbers must be entered:

34. There should be a separate numeric keypad in addition to the standard numeric keyset (on the top row of the keyboard). The advantage is that block sequences of numbers can be entered single-handedly while mixed alpha-numeric data can be typed in a conventional manner.

35. The lay-out of the keys on the numeric keypad should be compatible with telephone pads (1, 2, 3 on the top row) since push-button telephones are increasingly being used in conjunction with VDTs.

2.3 Workstation

The different components of a typical workstation are the desk, the chair, the documents, the document-holder, and the foot rest. They interact with each other and determine, to a large extent, the working posture of the operator. They thus contribute to comfort, well-being, and performance.

One main recommendation should be kept in mind concerning the workstation: it should be completely adjustable and organized to the operator's convenience. Possible workstation arrangements can be obtained, for example, by using paper and pencil sketches, scale, or full-size mock-ups.

2.3.1 Desk

Several parameters of the desk have to be analyzed: the size, height, thickness, depth, and colour. The value of these parameters should be defined on the basis of these three main factors: the tasks to be performed at the desk, the equipment to be used, and the anthropometric dimensions of the operators. The following issues should be considered: [2] [5] [6] [7] [8] [9] [14] [17] [18]

1. Sufficient space should be provided for handbooks, documents, copies, personal belongings, etc.

2. The work surface should be sufficient for the terminal, the devices (e.g., modem, calculator, telephone, pencils, etc.), the incoming and outgoing documents, the printouts and their use, etc. There should be enough room on both sides of the keyboard or screen to position the work documents.

3. The operator should be able to easily reach and operate the controls, especially the keyboard, when sitting at the terminal. The back row of the keys should be located at a distance of no more than 400 mm from the front edge of the desk. Simultaneously there should be a free area of

approximately 60 mm depth in front of the keyboard as a resting place for the hands. This is a safeguard against the "cutting action" between the edge of the keyboard and the operator's wrist.

4. Ideally the desk height should be adjustable (650-750 mm) to satisfy different operator heights. A desktop that permits the independent adjustment of the keyboard and the screen is more favourable because of its greater flexibility. It enables one to position his/her head in a way which minimizes the strain on the neck and shoulders. It also helps in the elimination of reflections.

5. The desktop height should be in the range of 690-720 mm. With a keyboard thickness of 30 mm, the working level would thus be 720-750 mm. This height enables the operator to have the forearms and hands horizontal when the hands are on the home row of the keys.

6. The desk should be as thin as possible, i.e. 30 mm, to provide the operator with sufficient knee clearance in height (between 650-690 mm) and a convenient working level.

7. The underside of the desk should be free of obstructions such as desk frame spars that might be harmful or hurt the operator. It should be wide enough (800 mm) to enable the operator to turn unobstructedly.

8. The desk should be deep enough (1000-1500 mm) to enable the operator to position the VDT in front of him/herself and adjust the reading distance to his/her convenience (800 mm for some operators). This depth makes provision for knee (450 mm) and feet clearance (800 mm).

9. The desktop colour should be matt finished: black or white colours, and any shiny coverings (e.g., glass) should be avoided. The reflectance from the desk surface should be kept to a minimum (0.4: optimum; 0.5: acceptable; 0.6: maximum).

10. Operators should be informed about the adjustments they can make, and encouraged to make them for more comfort.

2.3.2 Chair

Everybody agrees that the chair is of crucial importance for comfort and well-being at the workstation. It affects working posture, skelettal stress, and muscular fatigue. Its characteristics must be defined on the basis of several factors: the anthropometric dimensions of the users, the task requirements (e.g., alternation between sitting and standing, going back and forth between different work surfaces, etc.), the floor conditions (e.g., carpeted or not), etc. The following issues should be considered: [2] [6] [7] [8] [9] [14] [17] [18]

1. The chair should have a five point base for increased stability.

2. The seat height should be adjustable between 450 and 500 mm (varies between 350 and 550 mm in the literature). The limbs should be in the following position when the operator is sitting in a nearly upright position:
   - forearms and hands horizontal when the hands are on the keyboard;
   - thighs horizontal;
   - feet flat on the floor.

   In this posture, the stabilizing work required to maintain the sitting position is kept to a minimum.

3. The back rest should be adjustable in height and angle for pelvic lumbar support. The tension of the spring should be adjustable if the back rest is mobile in relation to the seat, or if the seat is mobile in relation to the chair pivot.

4. Dimensions of the chair could be as follows: seat depth: 350-450 mm; seat width: 380-400 mm; back rest height: 480-500 mm (some authors recommend 100-300 mm); back rest width: 280-320 mm; back rest tilt: 2° forward, 15° backward.

5. The seat and back rest covering should be rough textured for a better friction, and flexible to distribute the pressure and avoid pressure spots. The covering should permit air ciculation over the surface of the skin.

6. The front edge of the seat should be curved down to prevent it from cutting into the thighs in the sitting position.

7. The chair should have castors and/or a rotary facility if the operator has to move and/or turn around frequently (e.g. for accessing different work surfaces). These castors should be self-locking for chair stability (specially important on non-carpeted floor). They should be hooded for preventing any damage to the operator's clothes or shoes.

8. Arm rests that prevent the chair from fitting under the table should be avoided because the operator could be too far from the keyboard and not use the back rest of the chair.

9. All the adjustments should be capable of being easily, rapidly (a few seconds), and safely made from a seated position. The mechanisms should stay fixed when the chair is in the desired position.

10. Operators should be informed about the possibility of adjusting the height of the seat and the position of the back rest, and should have guidance to achieve optimum adjustments.

11. Operators should be informed about the characteristics of suitable chairs for the computer workstation and be involved in their choice.

2.3.3 Documents

80% of VDT operators also work with hardcopy. Due to the varying properties of the paper and text, different problems may be caused and lead to bad working postures and extra visual fatigue. The following issues should be considered to make the documents easier to read: [2] [9] [17] [18]

1. Matt paper should be used. Glossy papers should be avoided.

2. Dark ink should be used. Documents written with lead pen should be avoided because they tend to become unreadable due to glare at large viewing angles.

3. Good quality documents should be used: carbon or light photocopies should be avoided.

4. Hand-written texts should not be used because they may be difficult to read and lead to bad working postures.

5. White paper should be avoided (colours such as cream, pale yellow, and pale green should be used).

6. When appropriate, the formats of the documents (e.g., forms, bills, etc.) should correspond to the ones on the screen.

7. Lighting should be sufficient to permit good readibility but so as not to impair the readability of the screen.

2.3.4 Document Holder

A document holder can be very effective for reducing or preventing lateral movements of the neck, neck bending, twisting of the entire upper part of the body, and reflections from documents. The following issues should be considered: [2] [9] [17] [18]

1. A document holder should be provided and used if the operator frequently shifts vision between the documents and the screen to perform his/her work.

2. The document holder should be designed or chosen in relation to the characteristics of the documents (e.g., weight, dimensions) and to manipulations made by the operators (e.g., make additions or corrections, turn pages frequently, follow the text with the finger, etc.). Accordingly, the document holder should be sufficiently long, wide, and strong to maintain the document in place despite the manipulations.

3. The operator should be able to position the document holder as desired, i.e. on the right or left side of the screen, or between the screen and the keyboard (never above screen). It is well known that most VDT operators position their source documents where they can be most easily manipulated. Ideally the document holder should be next to, at the same level, and in the same plane as the display screen. In this way the reading distance is the same for the screen, and the line of sight is at a right angle to the plane of the document holder.

4. The document holder should be adjustable in height, depth, and inclination (about its vertical and horizontal axes).

5. Operators should be informed about the adjustments that can be done, and encouraged to make any if necessary.

6. The adjustments should be made easily, rapidly (a few seconds), and safely by the operators. The mechanisms should stay fixed once the document holder is in the desired position.

7. The document holder should have a bottom lip and/or a magnetic or other type of clip (depending on users' preference) to secure the position of the document.

8. The document holder should be matt finished.

9. Operators should be informed about the characteristics of document holders and be involved in their choice.

2.3.5 Foot Rest

A foot rest can contribute to making the workstation more comfortable for some operators. The following issues should be considered:

1. A foot rest should be provided if the user cannot have his/her feet flat on the floor when sitting at the terminal, or has blood circulation problems in the legs.

2. For more comfort the foot rest should be adjustable in height (between 0 and 50 mm) (varies between 0 and 150 mm) and in inclination (between 10° and 15°) (varies between 10° and 30°).

3. The adjustments should be made easily, rapidly (a few seconds), and safely by the operators. The mechanisms should stay fixed once the foot rest is in the desired position.

4. Operators should be informed about the adjustments that can be done, and encouraged to make any if necessary.

5. The foot rest should cover the entire leg area. Its width-depth should be about 400 mm (300 mm minimum).

6. The foot rest should be covered so as to enable comfortable movement of the feet without slipping.

7. The foot rest should stay stable when one is moving the legs or feet. Some authors recommend that it be secured to the floor or desk to prevent any sliding.

8. Operators should be informed about the characteristics of foot rests and be involved in their choice.

2.3.6 Working Posture

When the operator is sitting at the terminal in a nearly upright position, the following criteria should be satisfied for optional comfort (see Fig. 1):

1. The head is vertical or slightly inclined forward (20°).

2. The reading angle of the screen and the copy is about the same and around 90°.

3. The reading angle of the screen and the copy is about 20° below the horizontal plane (varies between 15° and 45°), or a bit more if the head is inclined.

4. The frequent changes of visual objects are within an angle of 15° and 30° relative to the normal viewing direction.

5. The distances eye-screen and eye-document are the same.

6. The spine is slightly arched and forward leaning when seen from the side.

7. The upper arms are vertical.

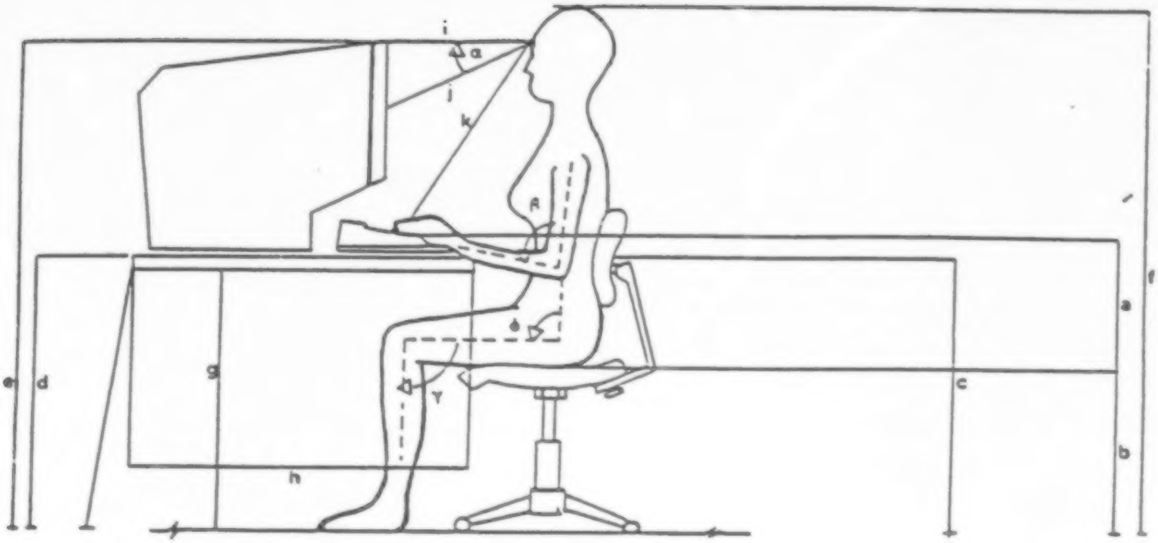

Figure 1 Dimensions of VDT Workstation[1]

a- level of work
b- height of chair seat
c- height of back-rest
height of work surface
d- height of desk
e- height of terminal
f- height of seated operator
g- height of clearance space for lower limbs
h- width of clearance space for lower limbs
i- horizontal viewing distance
j- distance between eye and center of screen
k- distance between eye and center of keyboard
α- visual angle relative to the horizontal
β- angle of forearm, arm
ϕ- angle of trunk, thigh
γ- angle of thigh, leg

Where documents are consulted, the eye-document distance should also be measured.

(From IRSST 1984, p. 16)

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[1] The posture and equipment shown on this drawing are incidental. The main purpose of Figure 1 is to illustrate the dimensions of the workstation that have to be taken into account.

8. The forearms and hands are horizontal when the hands are on the keyboard (elbow angle between 80° and 100°; wrist angle = 0°).

9. There is no twisting of the head and trunk.

10. The thighs are horizontal (femur-trunk angle between 100° and 105°).

11. The legs are vertical (thigh - leg angle 90°).

12. The feet are flat on the floor.

However, a workplace which requires the individual to maintain this single so-called 'optimum' posture, cannot in fact, be regarded as an 'optimum' workplace. The design of the workplace should encourage as many changes in position as possible[1].

2.4 Work Environment

The physical environment wherein computer workstations take place includes the room lighting, climate, noise, and static electricity. These elements must also be examined for an optimum comfort, well-being, and performance of the operators. This section also includes a section on the "position of the terminal" which deals with the position and orientation of the VDTs in the office environment.

2.4.1 Position of the Terminal

The appropriate positioning of the terminal is by far the most easily and effective way of eliminating screen reflections. The following issues should be considered when terminals are being positioned in an office: [2] [17] [18]

1. Terminals should be oriented such that the operator and the screen are not facing the window. The line of sight of the operator should be parallel to the windows. Since windows are the most important source of the reflections on VDT screens, they should be on only one side of the room.

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[1] "The frequently recommended upright right-angled seated position ... is probably not a product of science" ..." Staffel never gave any real explanation why this particular posture should be better than any posture. Nevertheless, this posture has been accepted ever since quite uncritically by all experts all over the world as the only correct one" (IBM [8] 1984, p. 44).

2. Terminals should be oriented such that the line of sight of the operator be parallel to the luminaires. This orientation eliminates shadow on the work surface.

3. Operators must not be facing shiny objects or annoying lamps.

4. The visual display should not be backed against a wall. Rather there should be an open area behind it to keep the maximum flexibility for adjusting the reading distance (800 mm for some people) and to allow the operator to have a viewing distance of at least 6 m when not looking at the screen or table.

5. The terminal should be located in a quiet area where there is no disturbance caused by conversation and the circulation of people, or by the circulation and noise of objects (e.g., carts).

6. The number of VDTs installed in a room should be as small as possible, and evenly distributed over the office area because of possible temperature and noise problems.

7. Terminals should be located far enough from air diffusers to protect the operators against air drafts on the head, neck, shoulders, and arms (these parts of the body are more sensitive to air drafts).

8. Operators should be able to get in and out of the work place easily, rapidly, and safely.

9. Operators should be informed about the different issues to consider for an optimum positioning of terminals, and be involved in the arrangement of their workplace.

2.4.2 Lighting

Lighting is undoubtedly of the greatest importance as regards the VDT workplace. It determines the ease with which a visual object can be recognized. The level required for a particular task depends on parameters such as the complexity and visual difficulty of the task, the equipment and job aids characteristics, the average standard of eyesight of those concerned, and the level of performance expected. A compromise is necessary to provide enough lighting to adequately illuminate source documents or other printed or written materials, without illuminating the VDT screen and reducing the contrast of the display. The following issues should be considered: [2] [5] [6] [7] [8] [9] [14] [17] [18]

1. VDT working areas should be illuminted with 300 to 500 Lux luminance (variations between 150 and 700 Lux). The lighting should be adjustable and operators should be encouraged to adjust the lighting level to their convenience.

2. Fluorescent lamps with the colour "neutral white" are those which are compatible with daylight and may be generally recommended. However, subjective preference should have the priority.

3. All lamps should have the same colour temperature because different temperature can produce an "irritating" twilight effect. Lighting should be uniform in the entire visual field.

4. To provide a more favourable light distribution, glare shielding of the lamps should be achieved (with filters or diffusers). The prismatic pattern and grid pattern types are more generally preferred. In all cases unshielded fluorescent lamps (i.e. those in which the tubes are visible with a viewing angle of 45° or less) must be avoided.

5. The luminaires should be installed in a direction which is parallel to both the viewing direction of the VDT operators and the windows in order to minimize the perception of glare. However, to prevent too uniform a structure in the layout of the workroom, this recommendation need not be rigidly adhered to.

6. The question of whether or not the luminaires should be recessed into the ceiling depends, among other things, on the likelihood of problems caused by glare. When the lamps are recessed, the luminance of the ceiling is less than when they protrude or are suspended below ceiling level thus permitting illumination of the ceiling itself.

7. In order to avoid stroboscopic effects between the display screen and the fluorescent lamps and between the lamps themselves, the use of a "duo-circuit arrangement"[1] is recommended, particularly in smaller work rooms. In larger rooms it is sensible to couple neighbouring lamps with different phases to treble the effective flicker frequency.

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[1] "In this type of circuit, a phase difference is introduced in the voltage supply to each lamp so that the maxima and minima of the light flux from the lamps no longer coincide." (Cakir et al., [2] p.180)

8. If there are windows in the workroom, drapes or blinds should be installed to protect against glare, especially in areas where terminals are located near windows or can be reached by light rays. Drapes or blinds are also important at night for preventing the reflection of illuminated objects inside the room.

9. The drapes or blinds should be bright, plain, and with a reflectance of more than 0.5 in order to match that of the wall surfaces inside the room. They should be opaque enough to stop the light rays and one must be able to close them completely. In large windows they should be divided in sections in order not to block entirely the view to the exterior.

10. Operators should be informed about the characteristics of appropriate drapes or blinds, and be involved in their choice.

11. The darkening of the room and the total shielding of the natural light should be avoided because in general it is psychologically unacceptable. Total or partial darkening of the room can only be recommended if the work being carried out requires such an environment.

12. If work requires reading documents: operators who wish to have an individual lighting on the work surface because the general lighting does not accommodate them even after adjustments, should be provided with individual desk lamps. This lighting should be operator adjustable in intensity (about 500 Lux), position, orientation, and be provided with glare shields.

13. Operators should be informed about the characteristics of appropriate desk lamps, and involved in their choice.

14. The reflection factors in the work office should be as follows: floor between 0.2 and 0.4; wall between 0.3 and 0.8; ceiling between 0.6 and 0.9; work surface: 0.4; keyboard: 0.15 to 0.17; keys between 0.2 and 0.7.

15. The luminance ratio in the central field of vision (e.g., between the keyboard and the screen, between the keys and the paper) should not exceed 1:3 (1:1 would be the theoretical ideal), and the luminance ratio in the peripheral field of vision should not exceed 1:10.

2.4.3 Room Climate

A comfortable room climate is necessary to maintain the feeling of well-being and full performance ability. However, what is understood by comfortable may vary from one person to another, and from time to time. It is difficult to generate one in which all employees are equally well satisfied. The following issues should be considered: [2] [6] [8] [9] [14] [17] [18]

1. These air conditions should be maintained stable during the working hours in the office environment: temperature between 21° and 23°C, 26° and 28° during the hot summer days; relative humidity between 50% and 55% (varies between 50 and 70%); speed of air movement less than 0.1m/sec.

2. The thermal emission from the VDTs should be taken into account when calculating the air conditioning requirements of the room. A VDT emits quite a lot of heat. The thermal loading may be between 30% and 150% greater compared with the situation without VDTs and increases very rapidly as the number of VDTs installed in the room augments.

3. The number of VDTs installed in the room should be as small as possible and evenly distributed over the office area. Equipment with low thermal emission should be purchased whenever possible.

4. The office must have an air conditioner system if several VDTs are installed in the same room and are close to each other.

5. The individual operator and their neighbours should be protected against the heat dissipated by VDTs and other equipment, the drafts around the neck, shoulders, and arms (these parts of the body are particularly sensitive to drafts), and local hot spots (e.g. under desks, in corners, etc.).

6. Operators should have the possibility to adjust the temperature, humidity, and speed of air movements to their convenience.

2.4.4 Noise

Noise problems at VDT workplaces usually stem from other items of equipment in the room (e.g., line printers, typewriters). However, there might be some irritating or distracting noise from the cooling fan or power supply of the VDT which can whir or hum. The following issues should be considered: [2] [5] [6] [8] [9] [14] [17] [18]

1. The operators should be able to work in a sufficiently quiet place (55 dB(A) in task areas requiring a high level of concentration, and 65 dB(A) in routine task areas).

2. The equipment noise levels (e.g. fans, power supply from the VDT, other equipment) should be no more than 5 dB(A) greater than the background noise level. The noise in the VDT room should not be affected by external noise sources (e.g., neighbouring rooms, or the outside world).

3. High frequency tones should be eliminated because they are particularly stressing.

4. If there are printers or teletypes: where possible, they should be removed from the immediate work place (and located in a special room), or encircled with sound panels; where impossible, they should be covered with a hood through which one can read without uncomfortable postures.

5. The operators should participate in the organization of their work environment in order to eliminate sources of noise.

2.4.5 Static Electricity

Special precautions should be taken to safeguard against the discharge of static electricity to the VDT chassis. It could be through treatment of the floor, carpets, furniture, etc. This problem is unpleasant and could be the cause of dermatitis (according to some authors). [2] [8] [9] [17] [18]

2.4.6 Other Aspects

The electrical supply cables and other services to the VDT and workplace should be out of the way of the operator. [2[[14] [17] [18]

2.5 Restrictions in Working with VDTs [9] p.64

1. Epileptics should not work with VDTs, especially if they are photosensitive. It seems reasonable to presume that persons who are subject to TV or other forms of visual reflex epilepsy may be prone to seizures when working with or in the vicinity of a VDT.

2. Persons with nystagmus should not work on VDTs.

3. For migraine sufferers, one author (Anderson) recommends no work with VDT. One Association (for Scientific, Technical, and Managerial Staff, England) recommends follow-up at close intervals, any increase in migraines being reported to the doctor.

4. For wearers of bifocal lenses, one author (Ostberg) recommends no work with VDTs. The members of "Colloque Vision Travail" (France) recommend that lenses be adapted.

5. For far-sighted people, the members of the "Colloque Vision Travail" recommend specially adapted glasses for VDT use. One author (Desnoyers) recommends that suitable glasses be provided for VDT use.

6. For persons over 45 or under doctor's care, one author (Anderson) recommends following doctor's advice.

2.6 Other Issues

The introduction and use of VDTs in the workplace generates important issues on the borderline between ergonomy and social policy. The following issues are some of those which will have to be addressed in any major VDT introduction. [2] [8] [9] [14] [17] [18]

1. Operators should be informed prior to the introduction of VDTs.

2. In order to be able to work with the system and the VDT, the operator should be taught at least:
   - how to operate the alphanumeric keyboard;
   - how to operate the function keyboard in the most appropriate way;
   - the main computer commands and coding instructions;
   - the facilities of the programs that are available to him/her and how they can be accessed and used.

3. Operators should be aware of the importance of comfort at work and know all the adjustments that can be done to obtain it.

4. Operators should be informed about the possibility of health problems being associated with work on VDTs.

5. Operators should be informed about special cleaning requirements for use with the screen, the chassis, and other components of the terminal. Operators should also know about quick and easy repairs they can carry out themselves (e.g. fuse change on their terminal).

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    This paper consists of an extensive discussion of important behavioural problems relating to system characteristics (performance, facilities, and on-line information) and interface characteristics (dialogue style, displays and graphics) with suggestions for solutions.

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    This review of the literature covers the physical aspects of the terminal and the various characteristics of the workplace, the work environment, and the organization of work with VDTs. It also covers the health problems that are often associated with VDTs. It gives recommendations for avoiding these problems.

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    This report presents a series of ergonomic recommendations for designing better computer terminals, work places, and work environments. It also includes recommendations about the organization of work with VDTs, the operators' needs for training and information, and the visual examination for computer users.

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    This excellent book consists of a collection of 15 papers which present norms, scientific results, suggestions, and recommendations for the design of man-machine systems. These papers are concerned with visual, auditory, and other sensory forms of information presentation, speech communication, man-machine dynamics, data-entry devices and procedures, design of controls, individual workplaces, work areas, training systems, etc.

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3. LITERATURE REVIEW: ERGONOMIC STANDARDS AND NORMS

3.1 Introduction

With the introduction of office automation, there has been a proliferation of ergonomic standards and guidelines. Governments, unions, scientific groups and corporations of many countries (in North America, East and Western Europe, Asia) have elaborated standards and guidelines. Even if, in most cases, the recommendations are similar to one another, there are divergencies and differences in their degree of precision.

Only a few countries (Germany [23], Norway [13], Sweden [11] [12], USA-Maine [4]) have created regulations on the use and design of video display units. In Germany, parallel studies were undertaken by Verwatungs-Berufsgenossenschaft (the TCA - Trade Cooperative Association)[1] and Deutsches Institut fur Normung[2] in the late 1970's and the early 1980's. Those documents have become legislation and they also have had a significant impact on the market. [9]

In Sweden, directives developed by the Swedish National Board of Health and Safety pertaining to prevention of eye fatigue and visual difficulties, became legislation in 1979. [11]

In United States, numerous states have Bills for V.D.T.'s and their workstations. At the Federal level, ANSI (American National Standards Institute) has recently produced draft standards for V.D.T. workstation. [4] The National Institute for Occupational Safety and Health (NIOSH) has recently issued recommendations on workstation design and health hazards of V.D.T. [4] There are also standards and guidelines for noise, temperature and ventilation developed by ASHRAE (The American Society of Heating Refrigeration and Air Conditioning Engineers) [1], and ASTM (American Society for Testing and Materials). However, those standards have been developed for new buildings. Consequently, problems arise when those conditions are existant in buildings prior to the advent of these new technologies. [18]

To prevent those problems from occuring, the Architecture and Building Sciences Directorate of Public Work Canada has designed an integrated workstation, the FUNDI (functional diagnostic research tools) which is presently under experimentation at the Federal

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[1] Para- governmental body which has responsibility for Health and Safety Assurance

[2] Private standards body similar to American National Standards Institute

Government. Data collected from FUNDI field trials will be used to develop better environmental standards. [8]

Moreover, the Canadian Standards Association (CSA), a non-profit organization, is preparing standards to apply to the physical and hardware environment of workstations. [4]

As regards to Provincial legislation, Ontario (Bills 149 and 169 in 1981) and Saskatchewan (Bill 30, in 1984-85) provide recommendations that not only address hardware characteristics but also work organization criteria. [7]

In this paper, we will review in detail the standards mentioned above as well as guidelines developed by scientific groups and unions. We will study the major health issues raised by the use of V.D.T.'s and at the same time, responses provided by governmental agencies and other associations.

3.2 Radiation

Many concerns about the issue of radiation have been raised by the scientific community and unions. Does the radiation from VDTs represent a potential danger for the user? Some have put forward the hypothesis that there exists a causal link between working with a VDT and experiencing health problems such as cataracts [22], teratological problems (birth defects) [4] or skin rashes [18] [20]*.

However, North American governmental agencies do not currently consider electromagnetic emissions from VDT's as a potential danger for users. For instance, Health and Welfare Canada's report of 1983 asserts that there is no reasons for any person to be concerned about the radiation effects of VDT's [4], and the National Institute of Occupational Safety and Health of the United States of America (NIOSH) has adopted a similar position regarding this matter. [4]

To review this question, we must first briefly review the range and the level of radiation currently emitted by VDT's and then compare these data to Canadian standards and norms for radiation emissions. VDT's emit x-rays as well as other radiation at lower levels. Radiation emitted by VDT's may be categorized into 1) ionized radiation (X-rays, ultra-violet) and 2) non-ionized radiation (infrared, radio frequencies, very low frequencies and extremely low frequencies).

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* For a complete overview of potential effects of radiations see: Dematteo Bob, HEALTH HAZARDS OF VDT's, 1984 [4]

3.2.1 Ionized Radiation

The level of ionized radiation produced by VDT's is far below the level allowed by the Canadian Emitting Devices Act (1979). In fact, it has been estimated that the level varies between 0.01 and 0.05 nRem/h (E.A. Cox, 1981) [2] while the international standard is established at a level of 0.5 nRem/h and the Canadian standard being 5 Rems/year for occupationally exposed groups and 0.5 Rem/year for the general population. [2] That is to say that the level of exposure is one tenth that of established standards.

3.2.2 Non-Ionized Radiation

With respect to radio frequencies, the Canadian Devices Act (1979) [4] established an upper limit of 1 nW/cm^2. Studies show that the degree of emission of radio frequencies emitted by VDT's is either non perceptible or far below current standards. [7]

However, few studies have measured the level of exposure of very low frequency (VLF) and extremely low frequency (ELF) radiation. Moreover, there is no existing Canadian standards upon which observations could be based. So there is no well defined border line to determine if this radiation represents a potential cause of illness among VDT's users. The major concerns arise from the fact that this radiation is pulsed and such radiation is believed to be more active than continuous radiation. Among the possible effects noted and linked in certain circumstances to radiation have been embryonic disorders, and central nervous system problems.

3.2.3 Regulations and Guidelines

3.2.3.1 Maintenance of VDT's

A consensus exists among governmental bodies (Norway; USA: Massachusets, Maine, Illinois; Canada: Ontario) (See annex 1) and non-governmental associations (scientific or unions) that a periodic checkup of the VDT is necessary in order to keep the device in a good working condition (and thus to prevent the possibility of a system fault causing undesirable radiation emissions). The frequency of required verification varies from semi-annual to annual.

3.2.3.2 Anti-radiation protection

With respect to potential effects of very low frequency radiation, views are more divided. As a matter of fact, no regulation exists concerning a shielding system. The only government recommendation about this issue is part of Ontario's Bill 169. [7] According to this law, no radiation but light is allowed and VDT's should be equipped with anti-radiation protection.

Non-governmental associations have argued, however for a shielding system to reduce electromagnetic frequencies emitted by VDT's. There is also significant pressure to pursue research in that domain in order to provide a better understanding of effects of VLF. [2] [7] [14] [15] [16]

3.2.3.3 Pregnancy

In Canada, both the Ontario and Saskatchewan governments have developed norms for pregnant woment who use VDT's at work. In both provinces, the pregnant woman can be reappointed elsewhere in the organization without losing her salary or advantages. The Treasury Board of Canada recommends that the pregnant woman can ask for a request of transfer. [21]

Certain non-governmental associations have recommended the transfer of pregnant women without any loss of salary or benefits. [2] [14] [15] [16]

In USA, the NIOSH is conducting an exhaustive study of VDT work and of reproductive problems among VDT users.

3.3 Visual Discomfort

3.3.1 Potential Factors

The question of visual discomfort induced by VDT work remains much debated. Many VDT users report complaints about visual strain, blurred vision and so on. However, no objective measure of these effects have been developed. Attempts have been made to qualify visual discomfort through the use of a set of indicators such as visual acuity, eye movements patterns and pupillary response for VDT tasks, but these have failed to show significant results. [14] [19]

Among the visual discomforts reported by VDT's users, can be distinguished ocular and visual problems. Ocular problems refer to sensitive and motor functions, i.e. eye strain, eye aches, burning eyes, tearing or itching eyes (IRSST). [7] Visual problems refers to the sensorial function of the eye. At this level, blurred vision and lowering of visual acuity are the most commonly reported problems. [14]

Factors that scientists put forward to explain the emergence of eye problems are complex. They are as much related to occupational factors as to individual characteristics. Among occupational factors, they take into account the design of the hardware, the type of task performed, the physical environmental features of the office. Individual characteristics include uncorrected eye sight defects, poor work posture and constitutional factors such as poor health, smoking habit, and age. [19]

When experts are developing standards and norms pertaining to the hardware environment, the VDT and the keyboard are considered the most important elements. In addition the furniture such as chair, table, desk, document holder and so on are significant elements which are also taken into account.

We will now review several standards and norms which have been designed to prevent visual and ocular problems.

3.3.1.1 Regulations and Guidelines

- The design of the hardware: the screen

Polarity of the screen: generally standards do not specify if the screen should have a positive or a negative image*. Sweden's regulations are the only ones which have addressed the matter and they state that VDT's should have a positive picture. [11] The other countries (Germany, USA) have not taken this factor into consideration or have not expressed any preferences. [5] [17] [23] In any case, it appears that the element to consider is the adjustment of the ambient light. Given that a negative image generates more luminescence than a positive one, the ambient light must be adjusted accordingly. For example, the Germans have determined that the ambient light should be set between 300 and 500 LUX if a negative image is being used while it should be set at 500 LUX if the image is positive. [9]

- Refresh rate: if the image produced by phosphor light is not refreshed constantly (approximate speed of 60 Htz) the image will flicker and jump. In order to avoid eye strain caused by a defective image, the standard is for a flicker-free screen (Sweden, Norway. [1] [2] [5] Germany even specifies a particular speed to refresh the screen. [9]

- Other characteristics: Germany has produced the most detailed standards pertaining to character height, width, contrast, pitch and distance between lines. [9] Some non-governmental associations (ANSI, PSAC) have also provided guidelines. [15] [17] But, in fact, those norms and guidelines vary considerably from one organization to another and to the degree that it is difficult to find any correspondence between what has been developed in different countries. [See Annex 1]

3.3.1.2 The Lightning Environment

As has been mentioned previously, the ambient light should be adjusted to the polarity of the screen. Even if they have not developed standards concerning this matter, most governmental and non-governmental organizations recommend that an adjustable individual lamp be provided.

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* However, governmental and non-governmental bodies agree upon the fact that brightness and contrast should be adjustable.

- Glare and reflected glare: this factor can be defined as the discomfort or impairment of vision experienced when part of the visual field is excessively bright in relation to the general surroudings. Reflected glare is a glare condition caused by the reflection of bright sources of light, e.g. windows, luminaires, etc., from illuminated surfaces within the field of vision.

The basic denominator of recommendations regarding this issue is that there should not be any reflection on the screen. But the way glare and reflected glare can be avoided is not always specified (Treasury Board of Canada, 1983). [21] Non-governmental associations (NIOSH, PSAC) recommend [14] [15] and German standards state that the VDT should be placed parallel to windows. [23] Saskatchewan's Bill [7] and the Swedish government [12] stipulate that walls and ceilings should have a flat finish. Another feature often mentioned is the shielding of the screen to avoid reflected glare. [See Annex 1]

3.3.1.3 Individual Factors

With the exception of the Treasury Board [21] and ANSI [17] which only set guidelines for the hardware and the physical environment, medical evaluation is taken into account by most organizations. The majority of recommendations mention that a pre-employment opthalmologic test be required in order to indicate the visual acuity of the employee and as well a periodic test to ensure that users have adequate vision. The recommended frequency of the periodic test varies between countries. Most usually, tests are scheduled on an annual basis. Germany sets the frequency of test as a function of user's age e.g. every five year for people under 45 years old and every 3 year for the others. [23]

Moreover, the Swedish and the Norwegian governments have ruled that corrective lenses should be adjusted to the viewing distance on VDT's and that employers should assume the resulting expense. [12] [13]

Work organization is another factor which may affect visual comfort. Because this factor is a key element related to stress, it will be discussed further in the text.

3.4 Musculoskeletal Problems

After visual discomfort, musculo-skeletal problems (back pain, neck and shoulder aches) are the major source of complaints reported by users. After observing subject's performances and comfort under different conditions, (sub-optimal and optimal workstation designs), significant differences have been noted; users working under sub-optimal conditions are less productive and complain more about visual and musculo-skeletal problems. [6] [14]

This suggests that musculo-skeletal problems are induced by inadequate workstation design in the sense that users adopt bad workpostures to accommodate themselves. The amount of time spent working on VDTs in a static posture also appears as a likely determinant factor of discomfort.

3.4.1 Standards and Guidelines

3.4.1.1 The Hardware Environment: The Furniture

Following those findings, there is a consensus among government agencies and non-governmental associations to make sure that all the hardware components are adjustable. This includes the chair (seat, back height and tension), the desk or the table and the document holder. Except for the recommendations of the Treasury Board [21] which suggest that the keyboard can be separated or integrated, all other recommendations and standards opt for a separated keyboard. [21]

Moreover, the Standards Council of Canada have drafted a set of standards for chairs. In short, the report states that:

1. the chair should be compatible with other items of furniture from the point of view of operator comfort and efficiency.
2. must be designed to avoid undue pressure on the underside of the thighs and back of the knees when the feet are on the floor.
3. must have a back high enough to support the upper back.
4. must have base that is both stable and unobtrusive.

European countries (Germany, Sweden) provide a detailed description of the seat and the table. [5] [7] [11] [23]

3.4.2 Pauses and Working Time

All North American and European standards provide pauses of at least fifteen minutes every two hours for users of VDTs. Some specify that pauses should vary depending on the type of task. For a task that requires intensive work using VDTs such as data input, users should have a fifteen minute pause every hour.

Concerning working time, the type of task is also taken into account in Canadian and European standards and guidelines. It is suggested that VDTs require a shorter working period (four to five hours a day). [See Annex 1]

3.5 Occupational Stress

Numerous studies on the health hazards of VDTs have looked into the occupational stress question. [3] [4] [7] [10] [14] Although, the causes of occupational stress are rather complex and not well defined, it seems that psycho-sociological factors (lack of autonomy, constraints in machine pacing and repetitive work) have significant effects on the level of stress experienced by users.

3.5.1 Work Organization Standards and Guidelines

We have already mentioned standards and guidelines pertaining to pauses and variety of work. Recommendations have also been developed to the effect that performance monitoring should be avoided as far as possible. The access to information (relating to the task or health hazards) and training in allowing the user to control his work environment, is also important in the reduction of stress. Thus, many governments and non-governmental bodies have included in their proposed guidelines specifications about information that should be provided to the user as well as training sessions. [See Annex 1]

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   2. how to shield your terminal and how to get it done;
   3. description of the ergonomic and stress hazards of VDTs;
   4. a comparison of VLF emissions from popular terminals;
   5. review of Canadian and U.S. legislation, current and proposed;
   6. a summary of provisions in Canadian and U.S. Collective agreements;
   7. trends in the U.S. and Canada in product liability;
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ANNEX 1

REGULATIONS AND GUIDELINES OF GOVERNMENTAL AND NON-GOVERNMENTAL ASSOCIATIONS

ANNEX 1. REGULATIONS AND GUIDELINES OF GOVERNMENTAL AND NON-GOVERNMENTAL ASSOCIATIONS

TEXT SOURCES ISSUES AREAS	TREASURY BOARD (Canada) [1]	ONTARIO [2]	SASKATCHEWAN [2]	DEPARTMENT OF COMMUNICATIONS (Canada) [10]	MAINE [2]	MASSACHUSSETS [2]	ILLINOIS [2]	GERMANY [3]	NORWAY [4]
LEGAL STATUS	Guidelines 1983	Bill 169 1981	Bill 30 1984-1985	Guidelines 1985	Law 1981	Bill 4537 1982	Bill 2397 1983	Law 1981	Law 1982 1982
1. FURNITURE									
1.1 Chair	adjustable: seat, back heights and angles	adjustable: seat & back height and tension	adjustable: seat & back, lombar support only	adjustable back rests for lombar support; no armrests, adjustable seat height	adjustable: seat height, back height & tension	adjustable: seat, back, lombar support	adjustable: seat, back, height, & tension	adjustable	adjustable
1.2 Desk or Table	adjustable height.	adjustable	adjustable	adjustable leg room; height 650-690 mm	adjustable	adjustable	adjustable	adjustable height: 72 cm width: 160 cm length: 120 cm	
1.3 Document Holder	adjustable to operator's requirements	adjustable angle	adjustable angle	adjustable				adjustable angle: 15° to 17°	
1.4 Footrest	recommended		adjustable		separated		separated	recommended	
1.5 Keyboard	separated or integrated	separated	separated and as thin as possible	(to consider features)				separate thickness:3 cm slope: 15°	

ANNEX.1. REGULATIONS AND GUIDELINES OF GOVERNMENTAL AND NON-GOVERNMENTAL ASSOCIATIONS

TEXT SOURCES ISSUES AREAS	SWEDEN [5]	ANSI [6]	NIOSH [2]	IRRST [2]	PSAC [7]	BOB DEMATTEO (OPSE 198) [8]
LEGAL STATUS	Law 1978	Guidelines 1985	Guidelines 1985	Guidelines 1984	Guidelines 1982	Guidelines 1984
1. FURNITURE						
1.1 Chair	seat height adjustable; angular adjustability of back support		adjustable height and back support	adjustable	adjustable: backrest, seat height, with five-base casters	adjustable backrest for lombar support; swivel chair with stable base
1.2 Desk or Table			adjustable height	adjustable	separate height adjustment. Adequate surface.	independently adjustable surfaces
1.3 Document Holder					adjustable	adjustable
1.4 Footrest					recommended	
1.5 Keyboard		separated slope of 0 to 25°	separated height: 740 to 750 mm	separate keyboard	detachable	detachable; weight, thickness, profile, color reflectance, key force, key travel, key top dimensions should be considered

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1. **FURNITURE**									
1.6 VDT									
- Background luminance								10 cd/m 2	
- Character contrast								min.: 3.1 pref.: 6.1 to 10.1 max.: 15.1	
- Character format	to consider							min.: 5 X 7	
- Character height	to consider		min. of 3mm.					18° of arc. 2.6 mm. (mm.)	
- Contrast and brightness control	adjustable	adjustable	adjustable	adjustable	adjustable	adjustable	adjustable	adjustable	adjustable
- Character width	to consider							50 to 70% of character height	

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1. **FURNITURE**						
1.6 VDT						
- Background luminance	adjustable 70 cd/m 2				adjustable, should be half the level of lux in a normal office (250)	
- Character contrast	pref.: 1.8 to 1.12 max.: 1.20	min.: 3.1c pref.: 7.1				from 3.1 to 15.1
- Character format	capital letters: 14x11					5x7 dot matrix
- Character height		about 1.4 to 1.25 for fixed column presentation			min.: 3.1 to 4.2 mm. max.: 4.5 mm.	min.: 3 mm. max.: 4.5 mm.
- Contrast and brightness control	adjustable	adjustable	adjustable	adjustable	adjustable	adjustable
- Character width	50 to 70% of character height	greater than 8% of character height				

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1. **FURNITURE**									
1.6 - Distance between the characters								one dot position or 10% of character height	
- Distance between the lines			1.5 x character height					one dot position or 10% of character height	
- Display unit	tilt and rotation capability		horizontal vision angle; between 10 40°	horizontal; the viewing angle should be 10 to 20° below the horizontal plane				if tiltable, no more than 5° forwards and 20° backwards. Vertical angle if not tiltable.	screen should be positioned so it is a suitable height to be seen by the user. Tilting of 15 to 20° may assure clearer image
- Maintenance of the VDT		every six months	every six months			To keep the equipment in condition. Keep a file of each device.	every six months	annually	once a year

ANNEX 1. REGULATIONS AND GUIDELINES OF GOVERNMENTAL AND NON-GOVERNMENTAL ASSOCIATIONS

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1. **FURNITURE**						
1.6 - Distance between the characters	20 to 30% of character height	min. of one stroke width				
- Distance between the lines	170% of character height					
- Display Unit	adjustable	vertical positioning greater than 40° from perpendicular to the display surface.	tiltable			
- Maintenance of the VDT	every six months			periodic control for radiation emission		

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1. **FURNITURE**									
1.6 - Polarity									
- Preferred colours								green through orange	
- Refresh rate				to consider				50 hz (neg. image) 80 hz (pos. image)	
- Viewing distance				450 - 700 mm.				500 - 800 mm.	45 to 75 cm
- Radiation									

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TEXT SOURCES ISSUES AREAS	SWEDEN [5]	ANSI [6]	NIOSH [2]	IRRST [2]	PSAC [7]	BOB DEMATTEO (OPSE 1984) [8]
1. **FURNITURE**						
1.6 - Polarity	positive image	either polarity acceptable		recommend positive polarity		
- Preferred colours						
- Refresh rate	flicker free; no after image	flicker free to at least 95% of the population.				
- Viewing distance	600 - 100 mm.		400 - 500 mm.			
- Radiation				anti-radition system; the actual norm be reduced to 0.01 to 0.05 mrem/h		

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2. LIGHTING ENVIRONMENT									
2.1 General lighting	suitable for viewing illuminated screens.		500 lux	500-700 lux				300-500 lux (negative image display) 500 lux or more for (positive image display)	
2.2 Individual lighting	adjustable	adjustable	required if working with written documents	presence of local lighting to illuminate reading of documents					supplementary lighting if required
2.3 Reflections	no reflections on the screen	provide screen shielding	provide screen shielding; Walls and ceilings have a matt finish.	placement of VDT screen not facing a window. Suitable colors and matt finish for equipment furniture and walls.	Illumination should be minimized by indirect general lighting. Provide screen shielding.	idem	idem	filters, coating, spray	

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2. LIGHTING ENVIRONMENT						
2.1 General lighting	200-300 lux.	min.: 200	500-700 lux.			max. of 300-500 lux.
2.2 Individual lighting	adjustable extra-lighting		should be adjustable by the user			should be provided to illuminate source documents
2.3 Reflections		luminance should be regulated to reduce the effect of glare	should be controlled through VDT placement (parallel to windows) and VDT glare devices		the office and the furniture and equipment should have a matt finish screen shielding	anti-glare screens, matte-finish surfaces, indirect lighting blinds on windows

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3. ENVIRONMENT OF THE OFFICE									
3.1 Temperature			adequate						
3.2 Humidity			adequate						
3.3 Noise	isolate accoustically or position at a distance equipment that generates high or distractive noise. Provide absorbing panels.	isolate accoustically or position the printer at a distance.							
3.4 Static Electricity			low as possible and controlled by adequate humidity						should be as low as possible. textiles and carpets should have anti-static treatment

ANNEX 1. REGULATIONS AND GUIDELINES OF GOVERNMENTAL AND NON-GOVERNMENTAL ASSOCIATIONS

TEXT SOURCES ISSUES AREAS	TREASURY BOARD (Canada) [1]	ONTARIO [2]	SASKATCHEWAN [2]	DEPARTMENT OF COMMUNICATIONS (Canada) [10]	MAINE [2]	MASSACHUSSETS [2]	ILLINOIS [2]	GERMANY [3]	NORWAY [4]
3. ENVIRONMENT OF THE OFFICE									
3.5 Radiation		no radiation but visable light							
4. WORK ORGANIZATION									
4.1 Breaks		15 min. every two hours	moderate work-15 min. every two hours. continuous work on VDT - 15 min. every hour.	15 min. work break mid-morning and afternoon is recommended	15 min./ 1 hr. scheduled for convenience of the employee. 15 min./ 2 hrs. as a minimum.	15 min./2 hrs. for continuous work but moderate visual workload. 15 min./1 hr. for continuous work intensive visual workload.	idem as Maine	one hour of uninterrupted work followed by a period of 15 minutes not using V.D.T.	short breaks every 2 hrs
4.2 Working period	variety of activities	maximum; 4 hrs/day						4 hrs daily max. or half a working day for continuous intensive visual workload.	50% of the working day for data entry work.

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TEXT SOURCES ISSUES AREAS	SWEDEN [5]	ANSI [6]	NIOSH [2]	IRRST [2]	PSAC [7]	BOB DEMATTEO (OPSE 1984) [8]
3. ENVIRONMENT OF THE OFFICE						
3.1 Temperature	19 - 23° C					
3.2 Humidity	30 to 70%				relative humidity be maintained above 50% level	
3.3 Noise					acoustic covers or locate printing facilities in a separate room	
3.4 Static Electricity	lowest possible; every carpet should have anti-static treatment			use anti-static material to cover the floors	proper grounding, anti-static floor carpetting and controlled humidity.	

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3. ENVIRONMENT OF THE OFFICE						
3.5 Radiation						
4. WORK ORGANIZATON						
4.1 Breaks	varies according to visual fatigue		intensive visual work like data input: 10 min./50 min.; 15 min./1 hr. for moderate visual work, 15 min./2 hrs	provide breaks - frequency and length should vary according to the task	regular and frequent rest 15 min/1 hr.	10 min./1 hr.
4.2 Working period				vary according to task	4 hrs.	4 hrs. a day on VDT vary activities

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4. WORK ORGANIZATION									
4.3 Performance monitoring		no performance monitoring.				performance results should be given to the employee	inform the employee before and give the results		should be avoided as far as possible
4.4 Information		allow employees to consult this law. Inform them about VDT hazards.			allow employees to consult this law. Inform on hazards related to VDTs.	inform employees six months before the implementation of VDTs.	idem as Maine	information about work with VDT. Information about ergonomics aspects.	employes should be given as much information as possible on the uses of new technology equipment at an early stage.
4.5 Training			pre-employment training						should have training

ANNEX 1. REGULATIONS AND GUIDELINES OF GOVERNMENTAL AND NON-GOVERNMENTAL ASSOCIATIONS

TEXT SOURCES ISSUES AREAS	SWEDEN [5]	ANSI [6]	NIOSH [2]	IRRST [2]	PSAC [7]	BOB DEMATTEO (OPSE 1984) [8]
4. WORK ORGANIZATION						
4.3 Performance monitoring					subject to negotiation	
4.4 Information					negotiations and/or consultations in relation to work load, work distribution and health and safety.	
4.5 Training					recommended	

ANNEX 1. REGULATIONS AND GUIDELINES OF GOVERNMENTAL AND NON-GOVERNMENTAL ASSOCIATIONS

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5. MEDICAL TEST AND PREGNANCY									
5.1 Pre-employment test			opthalmologic test required		obligatory for all employees	ocular exam	opthalmologic exam obligatory	opthalmologic test for every employee	
5.2 Periodic tests		every 6 months. results should be given to the employee		in specific cases, health evaluations may be required by departmental management.	opthalmologic exam once a year. Cost of the glasses paid by employer.	obligatory annual exam.	idem as Maine.	opthalmologic tests every 5 yrs for people less than 45 yrs old; every 3 yrs for 45 yrs and older.	annual visual test
5.3 Corrective lenses			visual correction adjusted to the task						adjust to viewing distance on VDT and cost paid by employer.
5.4 Pregnancy	request for transfer	can be appointed elsewhere without losing her salary or benefits	can be appointed elsewhere					possibility of not working with VDT.	

ANNEX 1. REGULATIONS AND GUIDELINES OF GOVERNMENTAL AND NON-GOVERNMENTAL ASSOCIATIONS

TEXT SOURCES ISSUES AREAS	SWEDEN [5]	ANSI [6]	NIOSH [2]	IRRST [2]	PSAC [7]	BOB DEMATTEO (OPSE 1984) [8]
5. MEDICAL TESTS AND PREGNANCY						
5.1 Pre-employment tests	obligator, for every employee		recommended	every year		
5.2 Periodic tests				recommended	eye examination each six months and paid by the employer	
5.3 Corrective lenses	cost of corrective lenses paid by employer				reimbursement by the employer for the cost of treatment and lenses	
5.4 Pregnancy				pregnant women can be appointed elsewhere or to benefit from the "retrait preventif"	transfers upon request of pregnant. VDT operator without loss of pay.	

*for description see text.

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Volume

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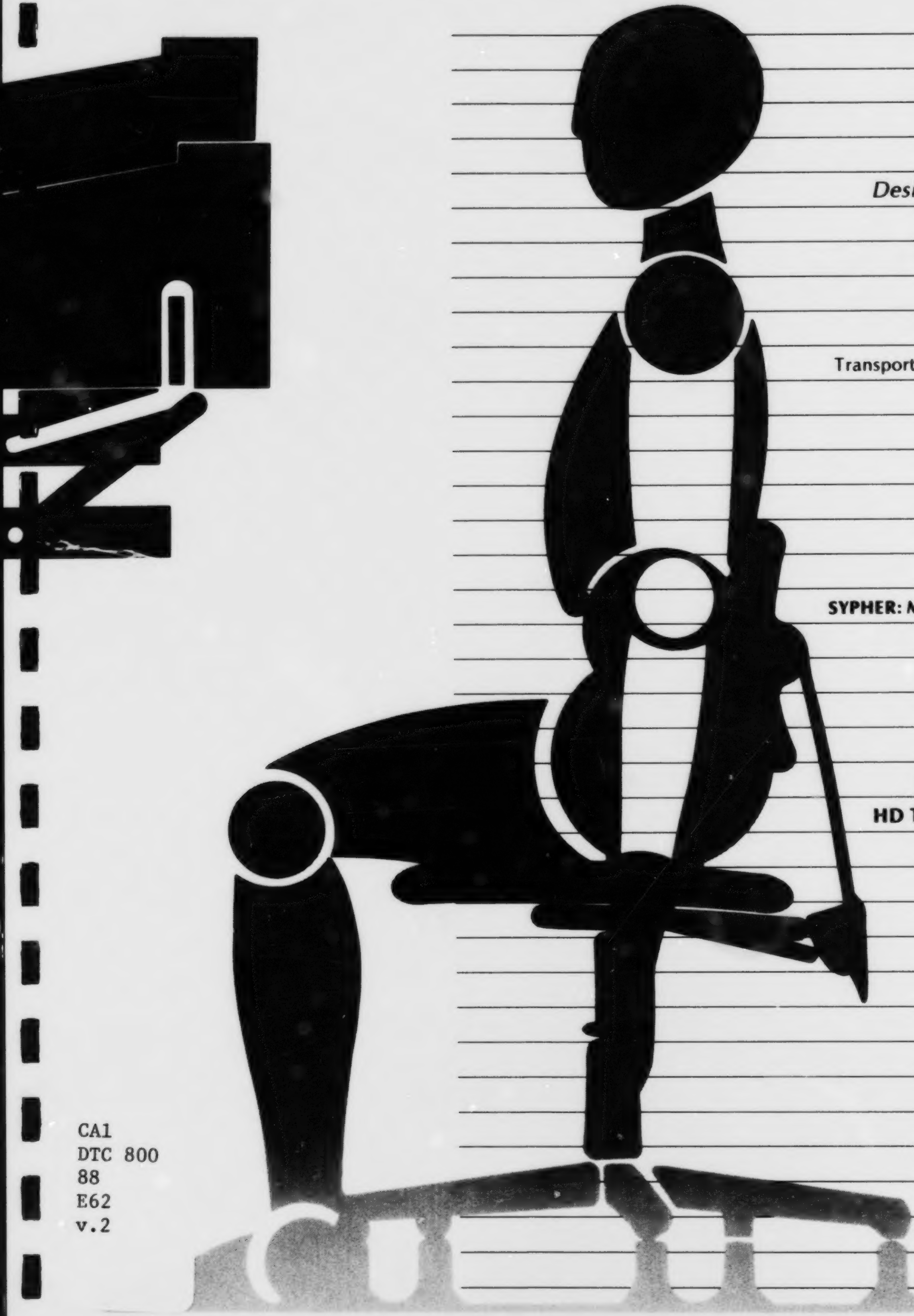

VOLUME II

Baseline Analysis,
Input Devices,
Design Recommendations
and Development of
Training Workstation

Prepared for the
Transportation Development Centre

June 1988

by
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Volume I: Literature Review
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16. TDC Project Officer
Barry Myers

17. Abstract

Volume I of this study is a comprehensive literature review summarizing the current state of knowledge and practice with respect to the ergonomic design and use of workstations and the ergonomy of computer aided learning. The literature review consists of three parts: a review of the ergonomy of computer workstations; a review of currently accepted ergonomics standards and norms with respect to workstation design and use; and a review of the ergonomy of computer aided learning.

Volume II contains four task reports. They are: Report on Baseline Analysis of Typical Training Tasks to be Performed at Training Workstation; Input Devices for Interactive Computer Systems; Design Recommendations; and Development of a Training Workstation.

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17. Résumé

Le tome I du rapport donne le résultat de la recherche documentaire faisant le point sur les connaissances et pratiques en matière d'étude et exploitation ergonomiques des postes de travail ainsi que sur l'ergonomie appliquée à l'enseignement assisté par ordinateur, EAO. Cette recherche se divise en trois parties: tour d'horizon des applications de l'ergonomie aux postes de travail en informatique; tour d'horizon des normes et lignes directrices utilisées en ergonomie, et applicables à l'étude et l'usage des postes de travail; revue des applications de l'ergonomie à l'enseignement assisté par ordinateur.

Le tome II renferme les quatre rapports suivants: Analyse de base des tâches d'enseignement types à être exécutées sur un poste de travail; Dispositifs d'interaction avec un ordinateur; Critères de conception; Mise au point d'un poste de travail en EAO.

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PREFACE

This report (Volume II), represents the synthesis of a series of task reports for the project "To Identify The Requirements For An Ergonomically Suitable Single-User Student Learning Centre For Electronic Systems Maintenance Technicians". A comprehensive literature review on the ergonomics of computer aided learning and workstation design is presented as a separate report (Volume I).

SUMMARY

In September of 1985, in order to foster the application of the most advanced knowledge in the area of ergonomics to the design of training and training technologies, the Transportation Development Centre of Transport Canada initiated a two-year project for the development of an ergonomically designed workstation for the training of electronic systems maintenance technicians.

The specific objective of the project was to develop a prototype of a workstation which incorporated the current state-of-the-art in ergonomic knowledge in such areas as workstation design and computer aided learning. (Workstation is the term used to describe a self-contained working environment, usually one where an individual is working with a computer terminal.)

The project began with an extensive review of the literature pertaining to the ergonomics of computer aided learning and of workstation design and a review of currently accepted ergonomic standards and norms with respect to workstation design and use. Recommendations with respect to the ergonomic requirements for the workstation design were developed as for example in the areas of lighting, air quality, heating, sound isolation, design and placement of the hardware and so on.

A review of the likely users of the system and the environments in which these systems might be placed determined that the system should be designed so as to be appropriate for a broad range of office environments constructed over the last 40 years and where extensive renovations may not have been undertaken.

The user population will be some 1200 technicians across Canada, primarily male, both French and English speaking, "in good physical condition" and of average height and weight. Also taken into consideration were users dependent on wheelchairs for mobility.

The issue of "embedded training" and the number and type of monitors required was examined and it was concluded that there would be a requirement for a training device over and above any training which might be available in "embedded" form in any of the new technologies being acquired. It was also concluded that for the foreseeable future, two screens would be required to accommodate the needs of the training system.

An examination was conducted to determine whether computer aided learning would satisfy the training requirements for the target user group. It was decided that attention would be concentrated on only a subset of anticipated technician training requirements (the RAMP system), because the new technical systems for which the technicians were being trained were not, for the most part, fully developed as yet.

A detailed task analysis of the RAMP system was conducted; the identified tasks were used as a basis for determining which would be the most effective teaching media for delivering the required training. It was concluded that computer aided learning is definitely able to provide instruction on most, if not all of the 373 RAMP training objectives.

A human factors review of most common input devices (keyboards, touchscreens, lightpens, mice, trackballs, joysticks, graphics tablets, and speech recognition) used for interacting with computers was undertaken. Their principal advantages and disadvantages and practical guidelines and criteria for selecting the best input device for a given application were documented. It was concluded that the different devices had a variety of advantages and disadvantages in such areas as ease of use, applicability to particular kinds of applications, and prerequisite knowledge and that no definitive selection could be made in advance of a detailed knowledge of the particular training modules which would be undertaken.

It was difficult to make definitive recommendations in some areas concerning the design and implementation of the workstation without knowing in more detail the nature of the software which will be used. However, certain recommendations can be made irrespective of the specific content of the courseware to be developed:

- the microprocessor should be sufficiently powerful to support the computer aided learning software and sufficiently reliable and robust for a range of office environments;

- the input/output devices should be the most advanced, proven devices and selected so as to facilitate computer use by inexperienced computer users;

- the workstation should be able to accommodate two persons working side-by-side;

- there should be sufficient space for the possible placement of one or two displays, one or two keyboards, a pointing device (such as a mouse), a modem, a printer, a microphone, paper, headphones, a telephone, a calculator, writing pads, pencils, rulers, a document holder, and a desk lamp;

- sufficient storage space should be provided for reference manuals, documents, printouts;

- the operator should be able to easily reach and operate the controls of the various devices listed above;

- the desk height should be adjustable and allow for wheelchair access;

- the chair should have a five-point base, with adjustable seat height and back rest, and castors;

- terminals should be oriented such that the operator and the screen are not facing the window;

- stable air conditions should be maintained during working hours (between 21°C and 28°C) and thermal emissions for the VDTs should be taken into account when calculating the air conditioning requirements of the room;

- special precautions should be taken to safeguard against the discharge of static electricity to the VDT chassis.

Three design options were developed incorporating the design recommendations. These were evaluated against the criteria developed with respect to ergonomic and design requirements and as a result a fourth option was identified with incorporated certain features of the three earlier options. A design sketch of the mock-up may be seen in Figure 1 below.

The workstation prototype -- CAL-STATION -- allows for a clearly defined area, providing semi-privacy without creating a feeling of confinment in an enclosed space. Any distractions in the environment such as bright lights, glare and background noise are controllable.

The CAL-STATION consists of a U-shaped wall system which supports the basic components of the workstation. The ceiling structure, work surface and monitors are all components firmly secured to the structural frames of the walls, but can be easily detached for replacement and maintenance.

The walls house all electrical wiring which can be accessed for servicing by removing the exterior panels.

The easy assembly of the system allows for rapid installation. CAL-STATION is to be identified as a learning place, not to impose, but to blend into an existing office environment.

The overall appearance is that of an open, light structure. The walls offer visual privacy to the user and create an acoustic barrier from the surrounding environment.

The form of the workstation is tapered to visually reduce its overall mass and to permit placing two or more units next to one another, forming a multiple workstation and thereby minimizing floor space.

The interior and exterior of the workstation are beige, which blends well various office environments and does not disturb the user while working at the station.

The work surface is mauve with low reflectance. All controls an handles are magenta, a bright colour visibly defining elements that can be adjusted by the user and indicating proper and safe positioning of hands for moving the components.

The overall size of CAL-STATION was based on the space required for a technican to comfortably perform all task and necessary movements of monitors without being wider than standard office desks. It also fits into areas with low ceilings (of approximately 2.7 m).

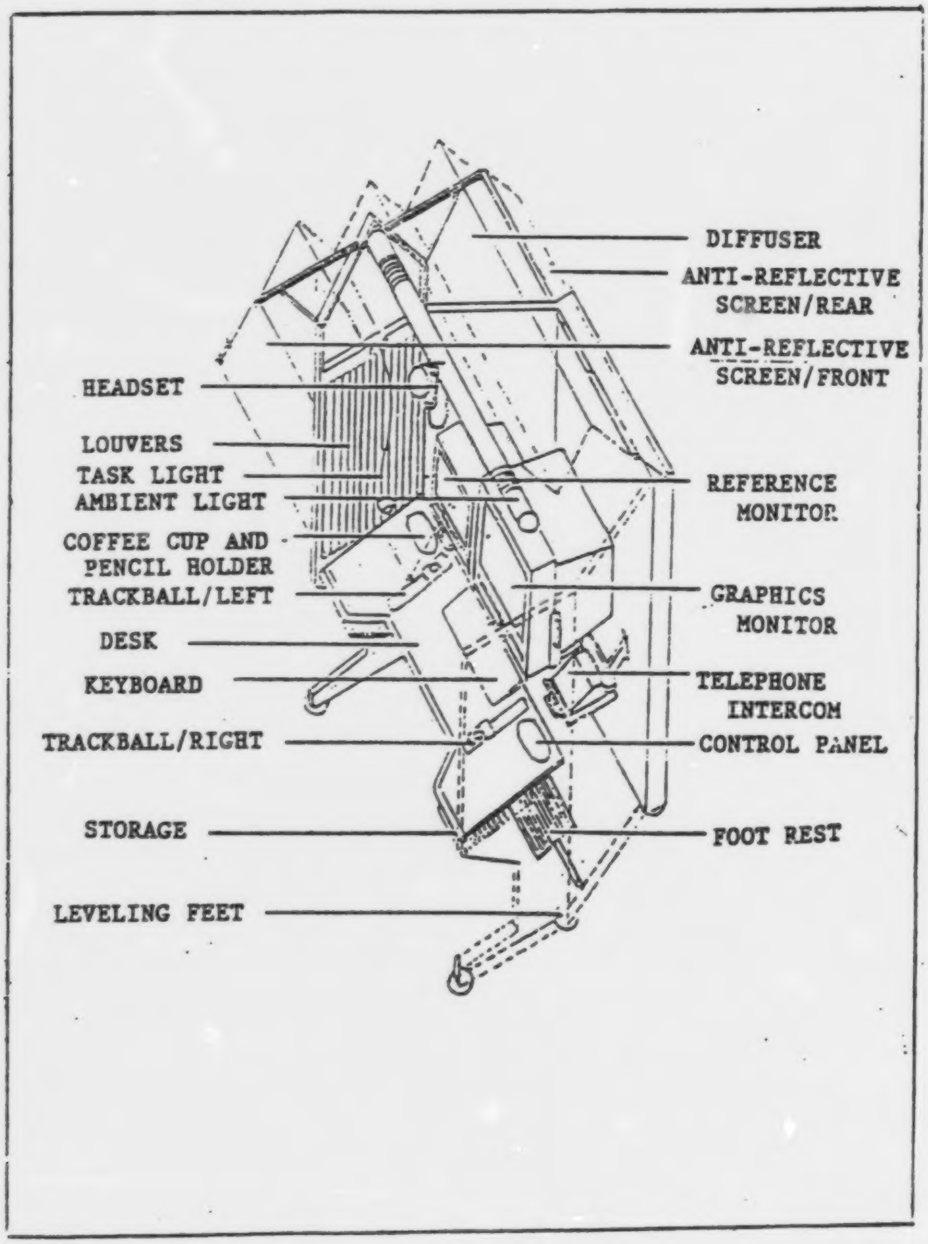

Figure 1. CAL STATION

SOMMAIRE

En septembre 1985, afin d'encourager l'application des techniques ergonomiques les plus récentes au domaine de l'enseignement et aux technologies connexes, le Centre de développement des transports de Transports Canada a lancé un projet d'étude et de développement d'un poste de travail ergonomique destiné à la formation des électroniciens aéronautiques.

Ce projet d'une durée de deux ans a eu pour objectif la réalisation d'un prototype de poste, incorporant toutes les connaissances accumulées en ergonomie et appliquées tant à l'étude d'un poste de travail qu'aux méthodes d'enseignement assisté par ordinateur, EAO, à y être utilisées. Le terme poste de travail désigne un endroit généralement autonome où sont concentrés les outils ou les aides informatiques aptes à l'exécution d'une tâche.

Le contractant a commencé par une recherche documentaire exhaustive sur les applications de l'ergonomie tant à l'EAO qu'à l'étude et l'usage d'un poste de travail, complétée par un tour d'horizon des normes et des lignes directrices utilisées en ergonomie et applicables aux domaines concernés. Cette recherche a débouché sur des recommandations relatives à certaines caractéristiques du poste envisagé, notamment en matière d'éclairage, ventilation, chauffage, isolement acoustique et touchant également le dimensionnement et la disposition des outils et des aides.

La prise en compte des utilisateurs éventuels du poste ainsi que des milieux dans lesquels il pourra être implanté, a montré que le poste en question devrait être adaptable à la plupart des bureaux construits durant les 40 dernières années et qui n'ont peut-être pas tous été rénovés en profondeur depuis.

La population cible des utilisateurs s'élève à quelque 1 200 techniciens canadiens, en majorité de sexe masculin, de langue francaise et anglaise, en bonne condition physique et dont la taille et le poids se situent dans la moyenne. Il a également été prévu qu'un certain nombre d'entre eux serait en fauteuil roulant.

La question de la "formation intégrée" et celle du nombre et du type d'écrans de visualisation à prévoir ont été abordées. L'examen de ces questions a montré qu'il serait nécessaire de disposer d'un outil supplémentaire permettant de parachever la formation initiale à l'exploitation des nouvelles technologies qu'il est envisagé d'acquérir, et qu'il serait préférable de pouvoir disposer au début de deux écrans de visualisation, du moins pour les besoins prévus dans le proche avenir.

Une autre question abordée a été celle de déterminer si la méthode d'enseignement assisté par ordinateur pourrait répondre aux besoins de formation des utilisateurs visés. La décision prise à cet égard a été qu'il serait préférable de se cantonner pour le moment à un volet de ces besoins, soit celui qui a trait au système RAMP, étant donné que les nouveaux systèmes sur lesquels les techniciens seront appelés à travailler à l'avenir ne sont pas, dans la plupart des cas, encore tout à fait au point.

Une analyse fouillée des tâches reliées au système RAMP a été faite; ces tâches ont servi à déterminer la méthode d'enseignement la plus appropriée. La recherche a montré que l'EAO est effectivement la méthode qui permettra aux responsables de satisfaire la plupart des 373 objectifs de formation rattachés au système RAMP.

L'étape suivante a été d'examiner sous l'angle de l'ergonomie les dispositifs d'entrée les plus répandus: clavier, écran tactile, crayon optique, souris, boule, manche à balai, tablette graphique et commande vocale pour communiquer avec l'ordinateur. La recherche a débouché sur une documentation touchant les principaux avantages et inconvénients de chacun de ces dispositifs et sur l'élaboration de lignes directrices et de critères pour la sélection de celui qui serait le mieux adapté à l'utilisation envisagée. Chaque dispositif possède des avantages et présente des inconvénients qui lui sont propres. Les caractéristiques comme la convivialité, la plus ou moins grande aptitude aux diverses utilisations et l'apprentissage préalable nécessaire peuvent varier de sorte qu'aucun choix ne saurait être fait de façon certaine sans une connaissance approfondie de l'application envisagée.

De même, il a été difficile de formuler des recommandations définitives sur certains aspects du poste de travail alors que le type de logiciel devant y être utilisé restait encore inconnu. Néanmoins, les recommandations suivantes ont pu être faites :

- le micro-ordinateur devrait être d'une puissance adéquate pour piloter le cours d'enseignement assisté par ordinateur, et avoir la fiabilité et la robustesse nécessaires pour résister à tous les milieux d'implantation prévisibles;

- les dispositifs d'entrée et de sortie doivent être les plus modernes et les plus fiables, et choisis pour la plus grande convivialité possible;

- le poste doit pouvoir accueillir deux personnes travaillant côte à côte;

- le poste doit pouvoir recevoir une ou peut-être deux unités de visualisation, un ou deux claviers, un dispositif d'interaction (une souris, par exemple), un modem, une imprimante, un microphone, des écouteurs, un téléphone, une calculatrice, des blocs-notes, crayons, papier, et règles, une corbeille et une lampe;

- il faut aussi de l'espace pour les manuels, la documentation, les imprimés;

- l'opérateur doit pouvoir saisir et actionner les commandes des dispositifs cités en toute facilité;

- le pupitre doit être réglable en hauteur et permettre l'accès d'une personne en fauteuil roulant;

- le siège doit s'appuyer sur le sol par cinq points d'appui munis de roulettes, il doit être réglable en hauteur et avoir un dossier également réglable;

- ni l'opérateur ni les écrans de visualisation ne doivent se trouver face aux fenêtres;

- des conditions ambiantes stables êntre 21 et 28°C doivent être maintenues durant les heures de travail. L'apport thermique des unités de visualisation doit être pris en compte dans le calcul des installations de climatisation;

- une protection spéciale doit être prévue contre le risque de décharge d'électricité statique vers le bâti des unités de visualisation.

Toutes ces recommandations ont été reprises dans trois architectures, dont l'évaluation en fonction des critères de conception et d'ergonomie retenus a débouché sur une quatrième où certaines caractéristiques des trois précédentes ont été reprises. La maquette de celle-ci est esquissée à la figure 1.

Ce prototype de poste, désigné CAL-STATION, découpe une aire de travail nettement définie, offrant un demi-isolement dont l'avantage est d'éviter un sentiment d'étouffement. Toutes les nuisances extérieures, comme les luminances trop fortes, l'éblouissement et le bruit de fond, y parviennent atténuées.

Une architecture à parois en U constitue le support sur lequel sont accrochés le plafond, le plan de travail et les unités de visualisation, et duquel ceux-ci peuvent être aisément décrochés pour les besoins de l'entretien et de la maintenance.

Dans les parois habillant l'architecture sont logés les fils électriques dont l'accès est possible par l'enlèvement d'un panneau.

D'assemblage facile et rapide, ce poste doit pouvoir être reconnu pour ce qu'il est: un lieu destiné à l'apprentissage; il doit donc s'harmoniser avec le milieu où il se trouve.

Tout en offrant une apparence ouverte et légère, le poste, grâce aux parois qui l'habillent, soustrait l'occupant aux regards et le protège du bruit environnant.

Des parois obliques enlèvent toute impression de lourdeur et permettent, en outre, d'installer plusieurs postes côte à côte et former ainsi une grappe multiposte, économisant ainsi l'espace de plancher occupé.

Les surfaces extérieure et intérieure du poste sont de couleur beige, qui se marie bien à tous les décors où il peut être implanté. Pour l'utilisateur, c'est une couleur très acceptable.

Le plan de travail est de couleur mauve, assez mate. Par contre, les commandes et leviers sont de couleur magenta, couleur brillante qui permet de définir le contour des éléments devant être manipulés par l'utilisateur, et à celui-ci de voir l'endroit exact où placer ses mains.

Enfin, le poste a été dimensionné en fonction de l'espace dont l'utilisateur a besoin pour exécuter les tâches prévues et pour manipuler les commandes à sa portée, sa largeur n'étant pas plus grande que celle d'un bureau de dimensions standard. Verticalement, sa hauteur lui permet de s'insérer dans des locaux où le plafond n'est qu'à 2,7 m du plancher.

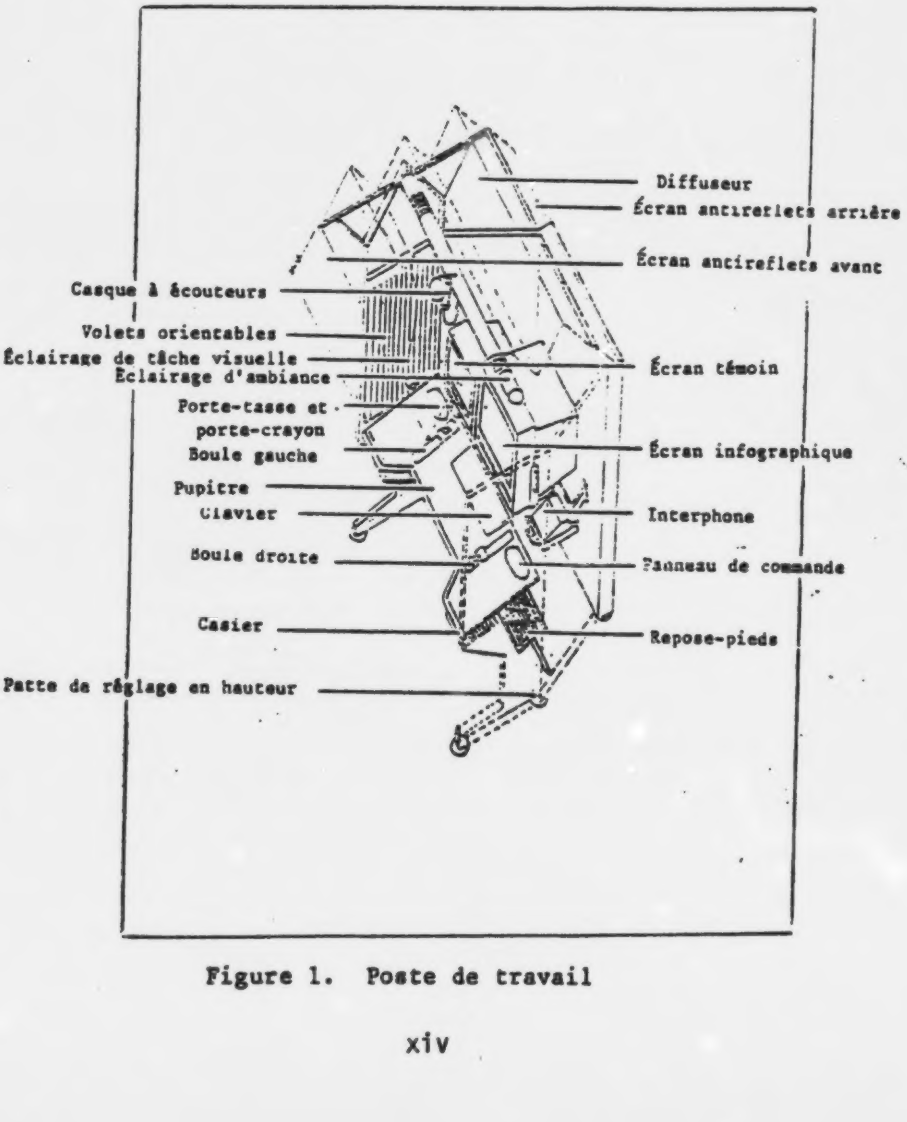

Figure 1. Poste de travail

TABLE OF CONTENTS

SECTION A

ERGONOMIC CHARACTERISTICS REPORT OF BASELINE ANALYSIS OF TYPICAL TRAINING TASKS TO BE PREFORMED AT TRAINING WORKSTATION FOR AIR TRAFFIC CONTROL MAINTENANCE TECHNICIANS

SECTION B

INPUT DEVICES FOR INTERACTIVE COMPUTER SYSTEMS

SECTION C

DESIGN RECOMMENDATIONS

SECTION D

DEVELOPMENT OF A TRAINING WORKSTATION

SECTION A

ERGONOMIC CHARACTERISTICS
REPORT OF BASELINE ANALYSIS
OF TYPICAL TRAINING TASKS TO BE PERFORMED
AT TRAINING WORKSTATION FOR
AIR TRAFFIC CONTROL MAINTENANCE TECHNICIANS

by

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in association with:

- Socioscope Inc.
- John-Marc Robert Ph.D.
- H.D. Thomas Communications

June, 1988

TABLE OF CONTENTS

1. INTRODUCTION AND BACKGROUND 1
  1.1 Introduction 1
  1.2 Background 1
  1.3 RAMP Project Overview 2

2. STUDY METHODOLOGY 6
  2.1 Introduction 6
  2.2 Selecting the Methodology 6
  2.3 Specific Methodology Application 7
    2.3.1 Overview 7
    2.3.1.1 Task Analysis Report 8
    2.3.1.2 Media Study 8
    2.3.2 Discussion 9
    2.3.2.1 Rationale for Using RAMP Data 9
    2.3.2.2 Developing Training Objectives 9
    2.3.2.3 Types of Objectives 10
    2.3.2.4 Media Analysis Data 12
    2.3.2.5 Learning Category and Sub-Category 12
    2.3.2.6 Selecting the Training Media 12

3. RAMP TASK ANALYSIS REPORT 17
  3.1 Organization of the TAR Summary 17
    3.1.1 Maintenance Levels 17
    3.1.2 Terminal Objective 17
    3.1.3 RAMP Equipment System and Sub-System 18
    3.1.4 Task Statement's Learning Requirement and Content .. 18
    3.1.5 Learning Category and Sub-Category 18
    3.1.6 Summary of Task Analysis Report Data on Learning Categories 18

4. RAMP MAINTENANCE TRAINING MEDIA ANALYSIS 32
  4.1 Introduction 32
    4.1.1 General Conclusion on CAL Viability 32
    4.1.2 Specific Conclusion on CAL Viability for RAMP Training Applications 32
    4.1.2.1 CAL Viability 32
    4.1.2.2 Some Observer/Supervisor Attention Still Required .. 39
    4.2 Additions to the Media Selection Decision Matrices . 39
    4.2.1 CAL with Interactive Video and Adjunt Material 39
    4.2.2 Requirements for System Portability 40
    4.2.3 Requirements for Centralized Collection and Dissemination of Course and Management Data 40
    4.2.4. Approach to System Cost Questions 40

References 40

APPENDIX A: Original 1975 Florida State University Media Selection Decision Matrices 42

5. ERGONOMICALLY SUITABLE I/O DEVICES 53
   5.1 Introduction 53
   5.2 Recommended I/O Devices 53
   5.3 Physical and Environmental Context 54
   5.4 User Profile for a Work Station for the Training of Electronics Technicians 54

6. SOFTWARE REQUIREMENTS 55
   6.1 Introduction 55
   6.2 Interactive Software Capability 56
      6.2.1 Minimum Functionality 56
      6.2.2 Authoring Facilities 57
      6.2.2.1 Text 57
      6.2.2.2 Sequencing 57
      6.2.2.3 Testing 57
      6.2.2.4 Graphics 58
      6.2.2.5 Audio 58
      6.2.2.6 Interface Methods 58
      6.2.2.7 Editing Methods 58
      6.2.3 Management Capabilities 59
      6.2.3.1 Types of Records 59
      6.2.3.2 Methods Used 59
      6.2.4 Documentation/Training 59
      6.2.4.1 Manuals 59
      6.2.4.2 Train-the-Trainer Support 59
      6.2.5 Communications 60
   6.3 Suitability for Use By Existing Trainee Population 60
      6.3.1 Ease of Use 60
      6.3.1.1 Minimum Reliance on the Keyboard 60
      6.3.1.2 Software Transparency 61
      6.3.1.3 Error Rates 61
      6.3.1.4 Legibility/Visibility 61
      6.3.2 Applicability for Bilingual Use 61
   6.4 Suitability of NATAL as an Authoring Language 61
   6.5 Alternative Authoring and Presentation Systems 62

7. CONCLUSIONS 67

LIST OF FIGURES

Figure 1-1 RAMP System Equipment and Designs 3
Figure 1-2 RAMP System Equipment and Designs 4
Figure 2-1 Sample Task Analysis Training Objective Hierarchy 11

LIST OF TABLES

Table 2-1 Description of Training Task Categories 13
Table 2-2 Sample Media Selection Decision Matrix 16
Table 3-1 Task Analysis Report Summary 19
Table 3-2 RAMP Task Analysis Report 31
Table 4-1 Rule Learning and Using 33
Table 4-2 Classifying/Recognizing Patterns 34
Table 4-3 Identifying Graphic Symbols 35
Table 4-4 Making Decisions 36
Table 4-5 Recalling Bodies of Knowledge 37
Table 4-6 Recalling Procedures and Positioning Movement 38
Table 6-1 Authoring System Selection Checklist 63

STEP I

RAMP TASK ANALYSIS REPORT:
A BASELINE UNDERSTANDING
OF TYPICAL TRAINING TASKS TO BE PERFORMED
AT TRAINING WORKSTATION
FOR AIR TRAFFIC CONTROL MAINTENANCE TECHNICIANS

1. INTRODUCTION AND BACKGROUND

1.1 Introduction

This study provides two reports relative to computer-aided learning (CAL). The first is a Task Analysis Report (TAR) on RAMP training requirements for Air Traffic Control Electronic Technicians. The second part of this Study is a report which analyzes the TAR to determine whether computer-aided learning can deliver the type of proficiency and refresher training required by electronics technicians responsible for maintaining RAMP equipment.

1.2 Background

In 1985, Transport Canada's Facilities Engineering and Systems Development (FESD) Branch published "Maintenance 2000" a Concept Paper. In its training section, the authors conclude that by the year 2000, with the new generation of air traffic control equipment coming on line across Canada, their Branch will have three unique training requirements:

1) training which will provide high degrees of systems knowledge;

2) training delivery systems which can be transported to the work site; and

3) training systems which will sustain technical proficiency that is otherwise expected to degrade since equipment reliability will reduce occasions for hands-on experience.

"Maintenance 2000" concludes that one of the means by which this training might be delivered is video and computer-aided learning (CAL) systems.

The purpose of this paper is to examine whether CAL media can in fact deliver the training in satisfaction of the FESD's three criteria. Requirements 1 and 3 above, dealing with the need for high degrees of system knowledge and the sustainment of technical proficiency, are the focus of this report. In the final chapter, we shall discuss computer-aided learning in light of the second stated requirement, transportability to the work site.

To arrive at our conclusions, we have conducted an analysis of the training requirements of one of the "new generations of Canadian air traffic control equipment". Known as "RAMP" for Radar Modernization Project, this equipment encompasses over forty (40) surveillance radars including their displays, support equipment, and facilities.

Since the following pages of this Study contain many references to RAMP equipment and the RAMP Program, it is appropriate to include in this section a brief description of the RAMP project and its equipment. The description will also acquaint the reader with the equipment terminology found in the Task Analysis Report Summary, Table 3-1.

1.3 RAMP Project Overview

The following paragraphs and the fold-out illustrations (Figures 1-1 and Figure 1-2 on the next pages) provide an informational and visual description of the RAMP program and equipment. Transport Canada's Radar Modernization Project is a major part of a nationwide effort to upgrade the Canadian Air Traffice Control System and technology while maintaining safety and reducing the workload of pilots and controllers. RAMP equipment will both replace and upgrade the existing national radar network.

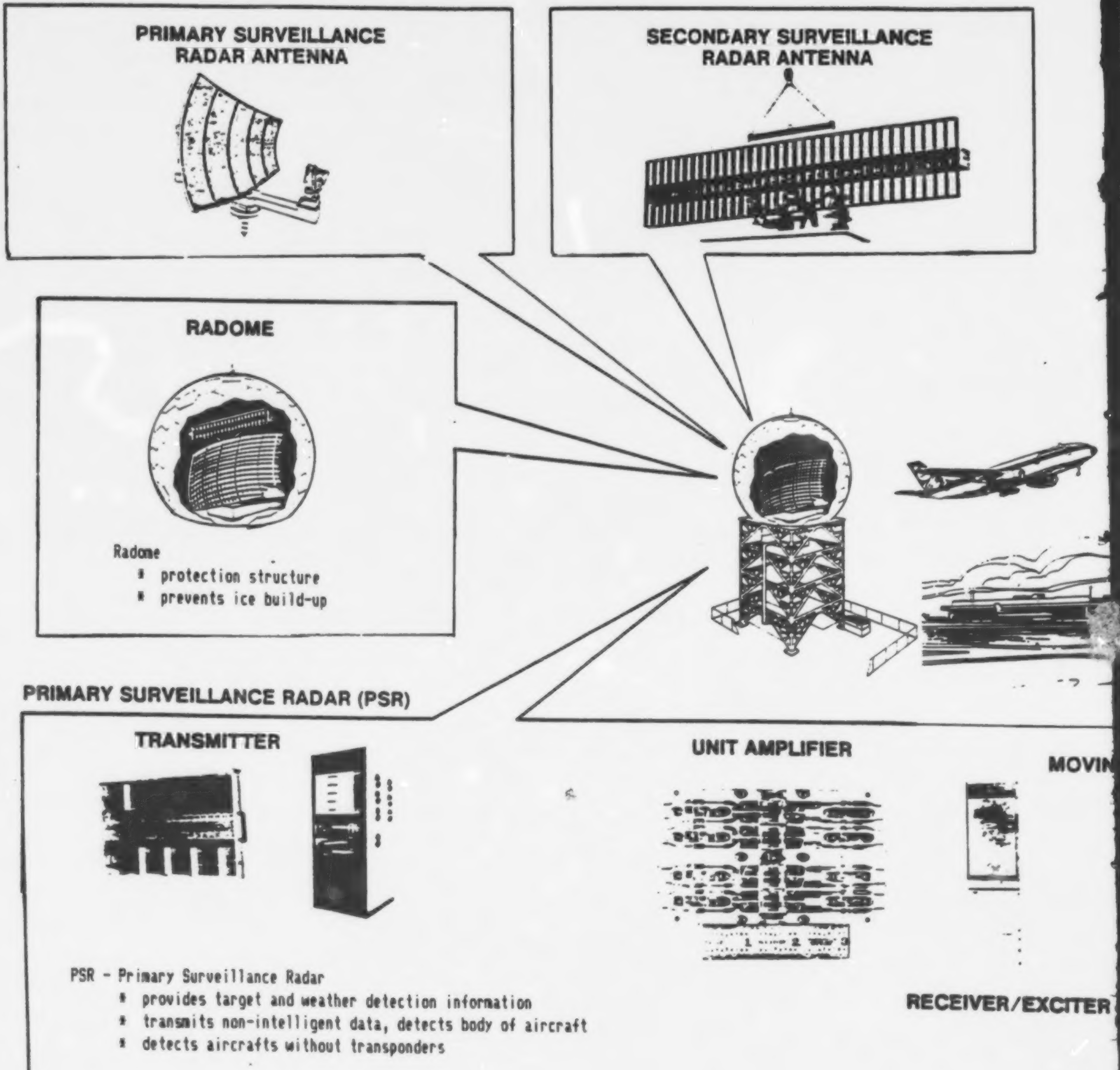
Many of the technology enhancements discussed in "Maintenance 2000" have been designed into RAMP. These enhancements are in the general areas of computers, signal and data processing, software, communications, display and solid-state microwave electronics. Specifically included in RAMP are:

- Modular Solid-state Final Power Amplifiers with automatic reconfiguration capability
- Structured Computer Program Methodolgy
- Real-time Air Traffic Control Software
- Autmated Fault Isolation Techniques

RAMP radars are ground-based, L-band systems. The first of these will be installed in 1987. By the early 1990's, twenty-two (22) major airports will have the new primary and secondary equipments. These will be backed up by a transportable system in Ottawa serving as an emergency replacement, and a system at the Transport Canada Training Institute in Cornwall. In addition, seventeen (17) other sites will be equipped with secondary radars to provide complete enroute coverage across Canada. The twenty-two (22) radars to be sited at major airports are called Terminal or Primary Surveillance Radars, abbreviated as PSR's. the seventeen secondary radars are called Independent Secondary Surveillance Radars or ISSR's. Special RAMP air traffic control displays will also be installed at major airports.

Remote site data communications and maitenance equipment are also included in the system. This equipment, and all above-mentioned radar installations, are backed up by a RAMP Maintenance Facility and a RAMP Software Support Facility.

RAMP System Equipment and Designs



PRIMARY SURVEILLANCE RADAR ANTENNA

SECONDARY SURVEILLANCE RADAR ANTENNA

RADOME

Radome
- protection structure
- prevents ice build-up

PRIMARY SURVEILLANCE RADAR (PSR)

TRANSMITTER

UNIT AMPLIFIER

MOVIN

RECEIVER/EXCITER

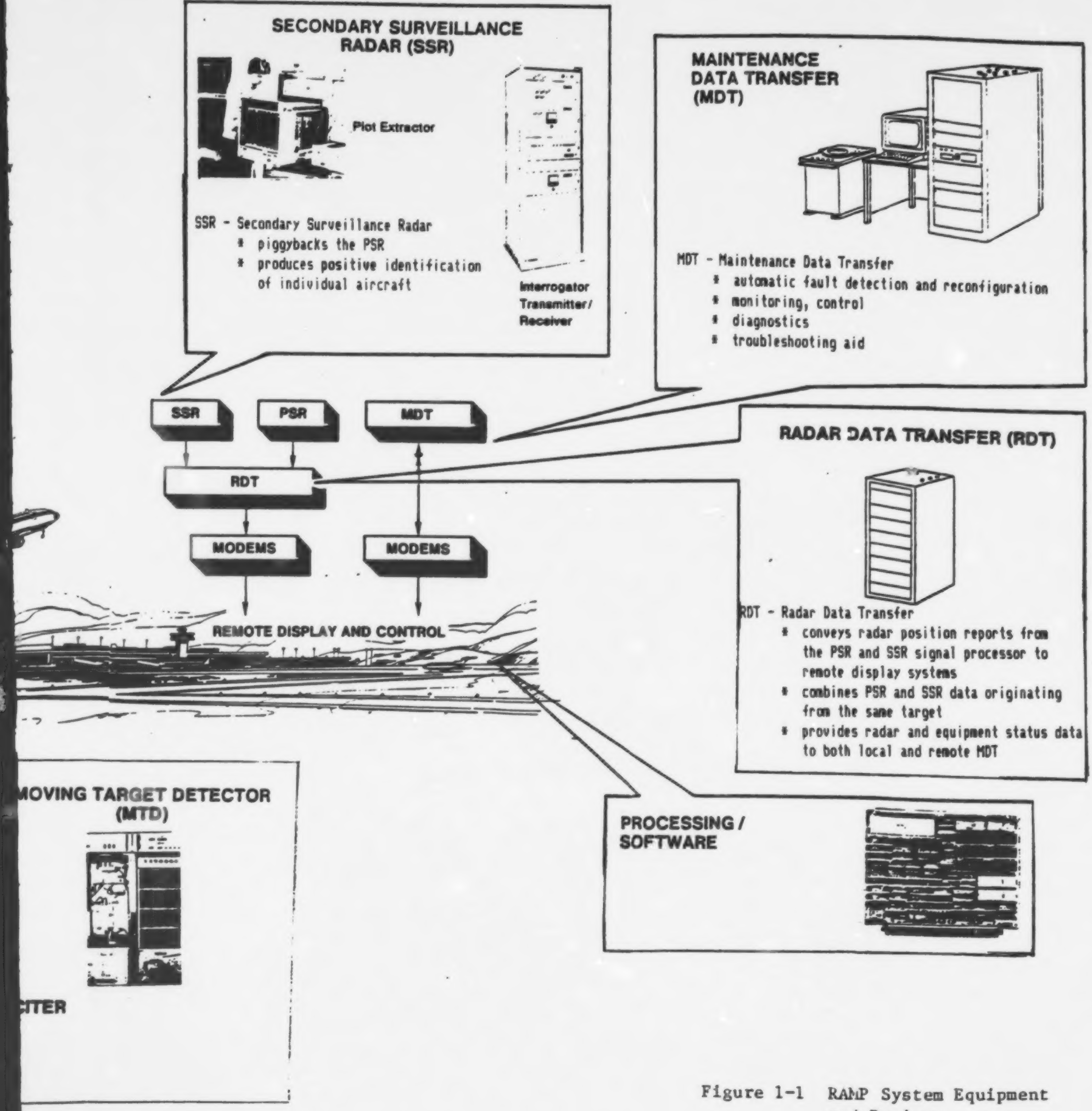
PSR - Primary Surveillance Radar
- provides target and weather detection information
- transmits non-intelligent data, detects body of aircraft
- detects aircrafts without transponders

RAMP - Radar Modernization Project

Antenna Pedestal Group - PSR and SSR antennas sit on top of the pedestal
- rotates antennas
- contains lubricating system

Microwave Component
- supports antennas
- "RF plumbing"

UPS


SECONDARY SURVEILLANCE RADAR (SSR)
Plot Extractor
Interrogator Transmitter/ Receiver
MAINTENANCE DATA TRANSFER (MDT)
SSR
PSR
MDT
RDT
MODEMS
MODEMS
REMOTE DISPLAY AND CONTROL
RADAR DATA TRANSFER (RDT)
MOVING TARGET DETECTOR (MTD)
PROCESSING / SOFTWARE
CITER

SSR - Secondary Surveillance Radar
- piggybacks the PSR
- produces positive identification of individual aircraft

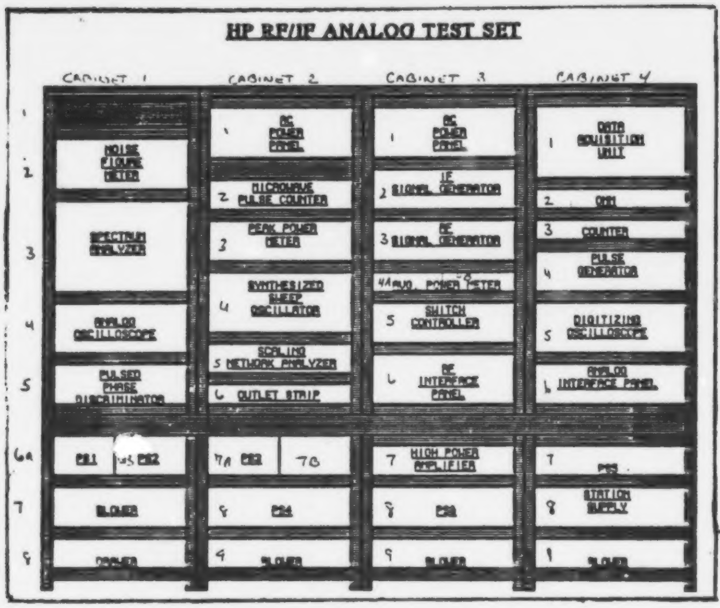
MDT - Maintenance Data Transfer
- automatic fault detection and reconfiguration
- monitoring, control
- diagnostics
- troubleshooting aid

RDT - Radar Data Transfer
- conveys radar position reports from the PSR and SSR signal processor to remote display systems
- combines PSR and SSR data originating from the same target
- provides radar and equipment status data to both local and remote MDT

Figure 1-1 RAMP System Equipment and Designs

UPS - Uninterruptable Power Supply
- designed so radar system will not experience power outage

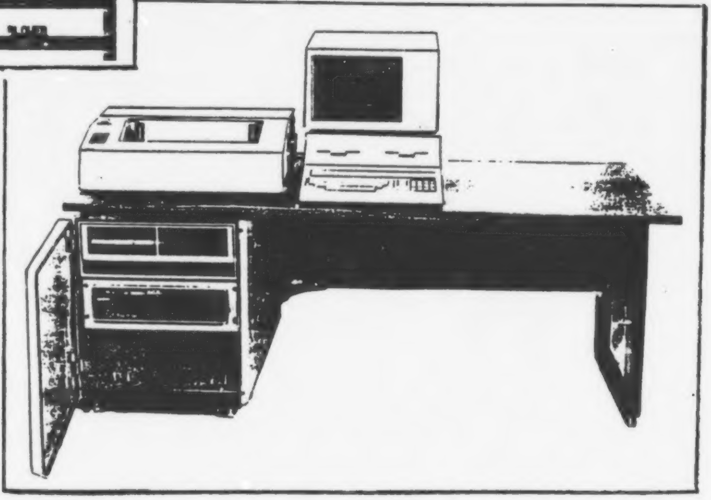
The three test sets are located at one maintenance support facility employing eight people. The facility acts as a central depot where the radar and display sites send bad circuit cards and RF modules. The test sets troubleshoot the bad circuit cards and RF modules.

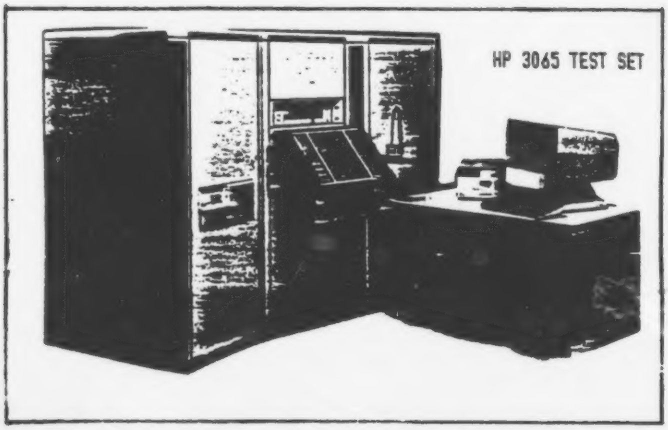

HP RF/IF ANALOG TEST SET

RF/IF TEST SET

RF/IF/ANALOG TEST SET

CONTROLLER

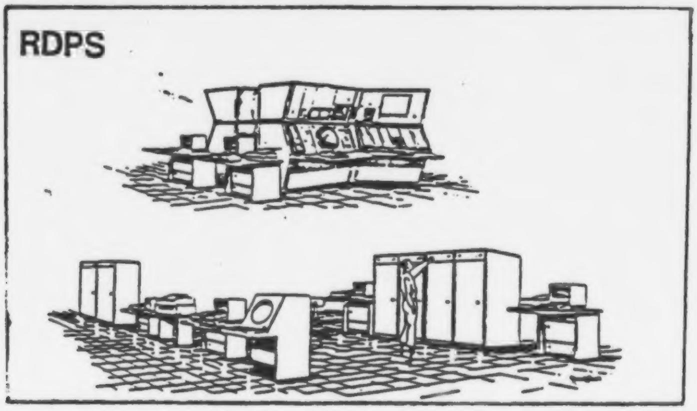


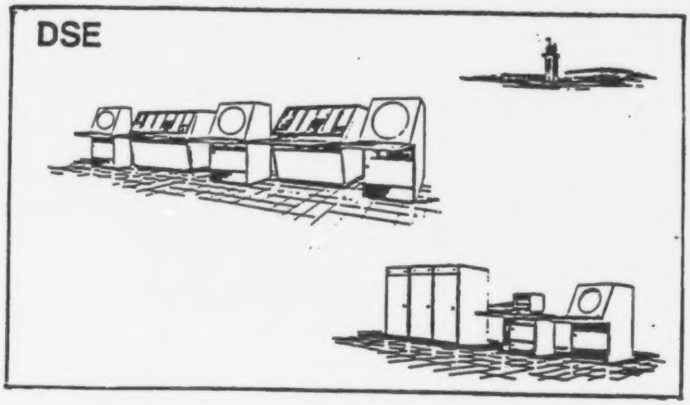

HP 3065 TEST SET

POWER SUPPLY TEST SET - picture not available

Power Supply Test Set - tests power supply
HP 3065 Test Set - tests digital in-circuit
RF/IF Test Set - tests RF modules

The display system receives information from the radar sites and transforms it into a useable format for the air traffic controller.





DSE - Display Site Equipment
RDPS - Radar Data Processing System
Processors - process information
OSAF - Operational Software Adaption Facility
DRF - Data Recording Facility
LAN Transceiver - Local Area Network - ties everything together into one network
VDU - Visual Display Unit
Maintenance Display - acts as a troubleshooting aid
Radar Simulator - simulates radar
MCP - Maintenance Control Position
DMS - Database Management System
TDU - Telephone Dial Up Unit
UPS - Uninterruptable Power Supply - designed so that display system will not experience a power outage
JETS - Joint Enroute Terminal System - takes information from radar in radar format and formats it for display
Comm Simulator - Communication Simulator

Figure 1-2 RAMP System Equipment and Designs

The equipment items covered in the RAMP Task Analysis include both the PSR's and ISSR's. The task analysis for RAMP displays at this moment is in development. Because of this, only a portion of this task analysis was available at the time this report was being written. The completed data, however, has graciously been made available to the authors of this study and has been incorporated in Table 3-1, pages 17 through 23.

2. STUDY METHODOLOGY

2.1 Introduction

As stated earlier, the objective of this study is to determine whether computer-aided learning (CAL) will satisfy the training requirements called out in "Maintenance 2000". For the purposes of this study, it has been assumed that the training requirements of RAMP equipment are in fact representative of the needs foreseen in "Maintenance 2000". Therefore, the approach used to determine the value of CAL is one based on instructural considerations particular to the RAMP Project.

The methodology most frequently used to determine the effectivenes of a teaching media is a process whereby the specific type of learning is allowed to drive the type of media which delivers the training. Stated simply, the way we learn knowledge or skills determines the kind of media that can effectively teach us that knowledge or skill. The correct starting point for a media analysis then, is the trained person himself, or, lacking this, a definition of this trained person. The manner in which training developers construct this definition is called job-task analysis. The requirements of the job(s) must be understood in order for the goals of training to be identified.

In the case of the RAMP Project, the "definition", the analysis of the operations and maintenance tasks, is well underway, with approximately 90% of the analysis process now completed. In summary form, it is included in this Study as the "Task Analysis Report" in section 3.0

2.2 Selecting the Methodology

The RAMP Task Analysis Report (TAR) states the job tasks and skills which must be trained and sustained throughout the life cycle of the new equipment. Effectively, the TAR is our job definition. Our judgements on the capability of CAL system to satisfy FESD training requirements will be developed from this baseline data.

In planning the approach to the study, we examined a number of methodologies which are frequently used in selecting media for training and education. The principal methods we considered were those proposed by Anderson (1983), Reiser and Gagne (1983), Briggs and Gagne (1979) and Branson, et al (1975).

The methodology chosen for this Study is that developed by Dr. Robert Branson and his team of Florida State University instructural technologies. Developed on contract for the U.S. Department of Defense as part of a complete instructional systems development scheme, the media analysis and selection process is part of Volume III of a five volume training development directive now known as the "Interservices Procedures for Instructional Systems Development". This material is the U.S. military's equivalent of the seven volume Canadian Forces Publication CFP 9000, the Manual of Individual Training.

This basic approach in determining appropriate training systems has recently been used in the Department of National Defence's CF-18 Hornet Program to determine media delivery system requirements for this aircraft's missile and automatic test set maintenance training. (See "Sidewinder AIM-9M and Sparrow AIM-7F [POP] Instructional Systems Development, Phse I Analysis: Media Plan"; [DND Contrct Number 2RF82-03092], Raytheon Service Company - Instructural Systems Center, March, 1984.)

The Florida State University methodology was selected for three reasons.

1) It uses job descriptive training objectives as the baseline data for selecting media.

2) It was designed especially for equipment operations and maintenance training applications.

3) It is configured so that a broad base of Task Analysis Report data can be synthesized quickly into valid training media decisions.

This Study, therefore, is presented in two parts:

1) The RAMP Task Analysis Report. The TAR identifies the job tasks and skills required to operate and maintain RAMP equipment, as described in this Study in Section 2, "Methodology" and in Section 3, "Task Analysis Report".

2) The Media Analysis. Our decisions on CAL have been made by analyzing the training data in the TAR, determining the types of learning involved the these job tasks and then, employing a special media decision matrix to determine the types of learning involved in these job tasks. Once these learning categories were known, we were able to make sound, RAMP-specific judgements on the effectiveness and viability of computer-aided training media.

This process is discussed in Section 2, "Methodology", and in Section 4, "Media Analysis".

2.3 Specific Methodology Application

2.3.1 Overview

The sequence of events followed in the development of the Task Analysis Report and the Media Study are listed below to provide the reader with a quick overview of these phases of the Study.

2.3.1.1 Task Analysis Report

1) RAMP task analysis and course documentation was collected from Raytheon's RAMP Program training staff. In-depth interviews were conducted with these experts on the various pieces of equipment.

2) Training objectives, a total of 373, were listed by level of maintenance and the type of terminal objective. (See Task Analysis Report Summary, Table 3-1)

3) RAMP training and subject matter experts then identified each performance or task statement (the actual statements of what is to be learned) and stated each in terms of its learning requirement and content.

4) Working together, instructional technologies and RAMP subject matter experts then analyzed the 373 task statements to determine each task's learning category and sub-category.

5) Learning category data was then summarized so that a preliminary conclusion could be drawn as to whether Computer-Aided Learning appeared to be suited to deliver RAMP training material. The preliminary conclusion was positive, and the decision was made to continue the Study.

6) The raw data in the form of 373 RAMP training objectives was then listed in the Task Analysis Report Summary Table. This concluded the development of the Task Analysis Report.

2.3.1.2 Media Study

7) The first step in the Media Analysis was to modify the Decision Matrices to be used for Media Selection (see section 4.0, Table 4-1) to reflect only CAL, since other types of training media are not the focus of this Study. Additionally, new administrative criterion was added to the matrices, based on the transportability requirements and remote location of work sites noted in "Maintenance 2000".

8) Each of the six Media Selection Decision Matrices were filled in to reflect the RAMP training requirements derived from the RAMP Task Analysis Report Summary, Table 3-1.

9) Based on the comparison of this data, our conclusions were developed and stated.

2.3.2. Discussion

2.3.2.1 Rationale for Using RAMP Data

The baseline job performance data needed to start the media analysis process is the detailed listing of the training objectives found in the Task and Skill Analysis of the job being trained. It was decided to use the training task analysis and objectives developed for teaching RAMP radars and displays for three reasons:

1) RAMP equipment, in terms of its reliability and expected siting, is the type of hardware which the authors of "Maintenance 2000" had in mind when they forecast the three new training needs noted in section 1.2 of this Concept Paper.

2) The Task and Skill Analysis work on RAMP equipment, developed for key personnel training at the Transport Canada Training Institute (TCTI), is 90% completed as of this writing.

3) The RAMP task list is large, numbering over 370 objectives, and thus presents a comprehensive sampling of the type of learning categories and training objectives. It is our belief that the FESD Branch can expect these objectives to be typical of those required to learn the operation and maintenance of the new generation of airways equipment.

RAMP task analysis data was provided through the courtesy of Raytheon Company's Equipment Division training staff in Wayland, Massachusetts. The specific data needed was the complete body of training objectives developed as the basis for the training of key personnel at TCTI. These training objectives contain the statements of actual job performance and behavior ... the raw data of a media study.

2.3.2.2 Developing Training Objectives

In order to fully understand the Task Analysis Report, it is important that the reader understand how a training objective is developed and the role of these data items in the development and conduct of training and on-job performance.

According to the Department of National Defence's Manual for Individual Training (CFP 9000), a training or performance objective is a "statement that describes, in a detailed and precise way, what the trainee must accomplish in order to fulfill the job requirement". A correctly written performance objective has three parts:

1) A Performance Statement that describes what the trainee must do when tested, such as remember information, disassemble a device, navigate a boat, etc.

2) A Conditions Statement tht describes the conditons present when the task is normally performed .. the important conditions under which the trainee must demonstrate his competence. Important conditions are such things as whether the task is performed with or without the aid of a manual or set of instructions or from memory, whether it is performed at night of during the day, alone or with a co-worker, etc.

3) A Standards Statement which describes how good one's job performance has to be in order to achieve success, to get a passing grade, or to attain a particular job status or qualification.

A typical electronics training objective might read:

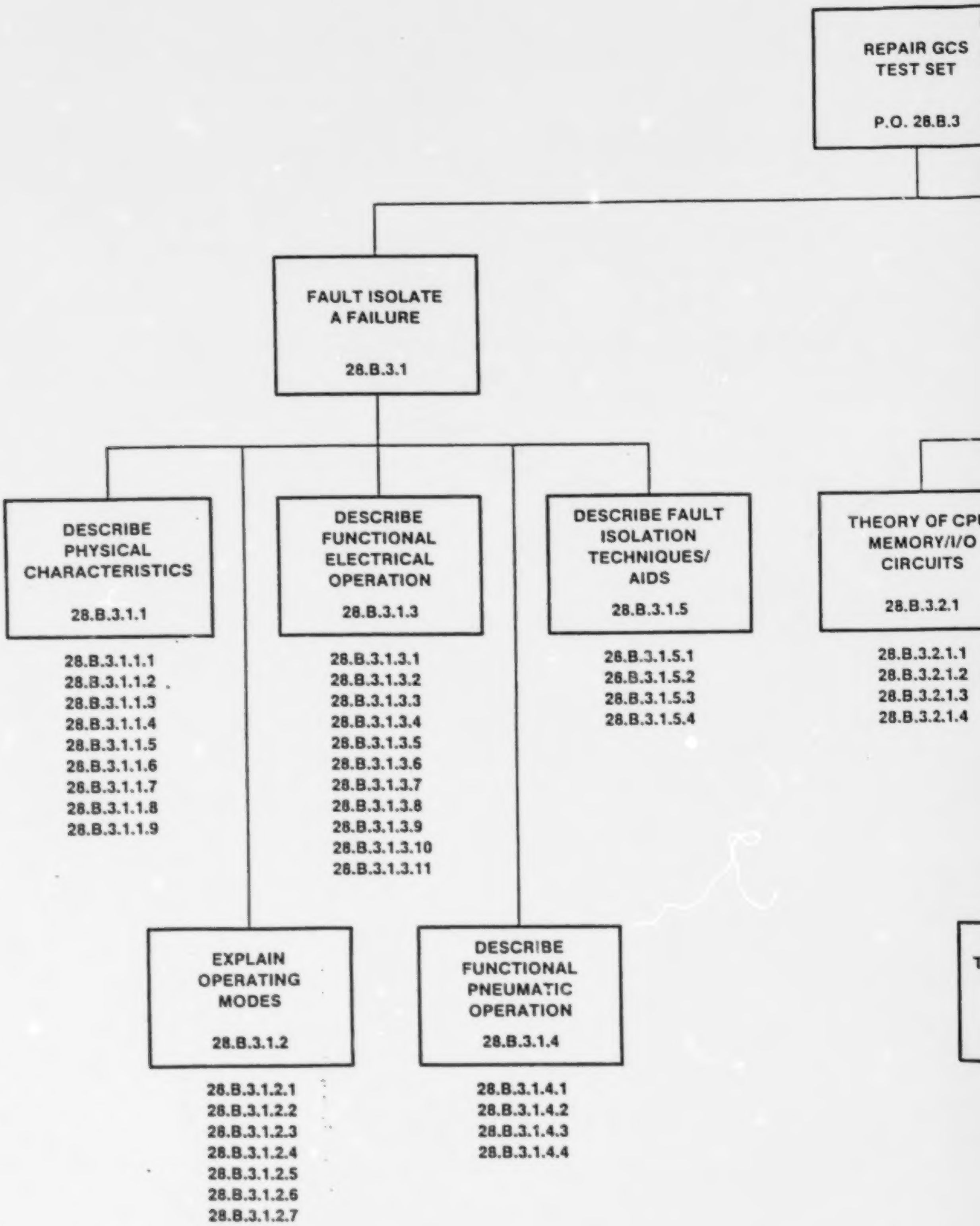
"Fault isolate the receiver-transmitter unit to the printed circuit board level (the Performance Statement), using the correct technical manuals and standard tools and commercial test equipment, (the Conditions Statement) without assistance and without safety violations, within ninety (90) minutes (the Standards Statement)."

As can be readily seen, these types of training objectives clearly state the level of proficiency that a trainee must achieve in order to be called "trained", that is, to graduate. Moreover, the standard of performance derives from a job requirement, and is not a level of achievement set arbitrarily by an instructor or school administrator. Therefore, as long as we use RAMP training objectives as our baseline data, we are actually building our conclusions upon the reality of what it takes to operate and maintain RAMP equipment.

2.3.2.3 Types of Objectives

In a Task Analysis Report, training objectives are often referred to by different names. These names are usually directly related to the hierarchical listing of training objectives. Much like the hierarchical equipment trees familiar to most electronics technicians and electrical engineers, training objectives evolve in the same systematic manner, particularly in equipment training when the trainee must learn each component. Similiarly, they can be graphically depicted, as illustrated Figure 2-1 on the next page.

In this illustration (Figure 2-1), the abbreviated training objectives, "Repair GCS Test Set" is called a "terminal objective", or T.O., because it repesents the end or final ability that is achieved when a trainee can satisfy all the training objectives listed below it. Objectives listed directly under the terminal objective are called "enabling objectives", or E.O.'s. In Figure 2-1, "Fault isolate a failure" in the GSC Test Set is an example of an enabling objective. Objectives listed beneath an enabling objective are called "sub-enabling objectives". In Figure 2-1, "Explain the operating modes of the GCS Test Set" is an example of a sub-enabling objective. Achieving the Performance standards of all enabling and sub-enabling objectives "enables" a trainee to meet the performance requirements of a terminal objective.


REPAIR GCS TEST SET
P.O. 28.B.3
FAULT ISOLATE A FAILURE
28.B.3.1
DESCRIBE PHYSICAL CHARACTERISTICS
28.B.3.1.1
28.B.3.1.1.1
28.B.3.1.1.2
28.B.3.1.1.3
28.B.3.1.1.4
28.B.3.1.1.5
28.B.3.1.1.6
28.B.3.1.1.7
28.B.3.1.1.8
28.B.3.1.1.9
DESCRIBE FUNCTIONAL ELECTRICAL OPERATION
28.B.3.1.3
28.B.3.1.3.1
28.B.3.1.3.2
28.B.3.1.3.3
28.B.3.1.3.4
28.B.3.1.3.5
28.B.3.1.3.6
28.B.3.1.3.7
28.B.3.1.3.8
28.B.3.1.3.9
28.B.3.1.3.10
28.B.3.1.3.11
DESCRIBE FAULT ISOLATION TECHNIQUES/ AIDS
28.B.3.1.5
28.B.3.1.5.1
28.B.3.1.5.2
28.B.3.1.5.3
28.B.3.1.5.4
THEORY OF CP
MEMORY/I/O
CIRCUITS
28.B.3.2.1
28.B.3.2.1.1
28.B.3.2.1.2
28.B.3.2.1.3
28.B.3.2.1.4
EXPLAIN OPERATING MODES
28.B.3.1.2
28.B.3.1.2.1
28.B.3.1.2.2
28.B.3.1.2.3
28.B.3.1.2.4
28.B.3.1.2.5
28.B.3.1.2.6
28.B.3.1.2.7
DESCRIBE FUNCTIONAL PNEUMATIC OPERATION
28.B.3.1.4
28.B.3.1.4.1
28.B.3.1.4.2
28.B.3.1.4.3
28.B.3.1.4.4
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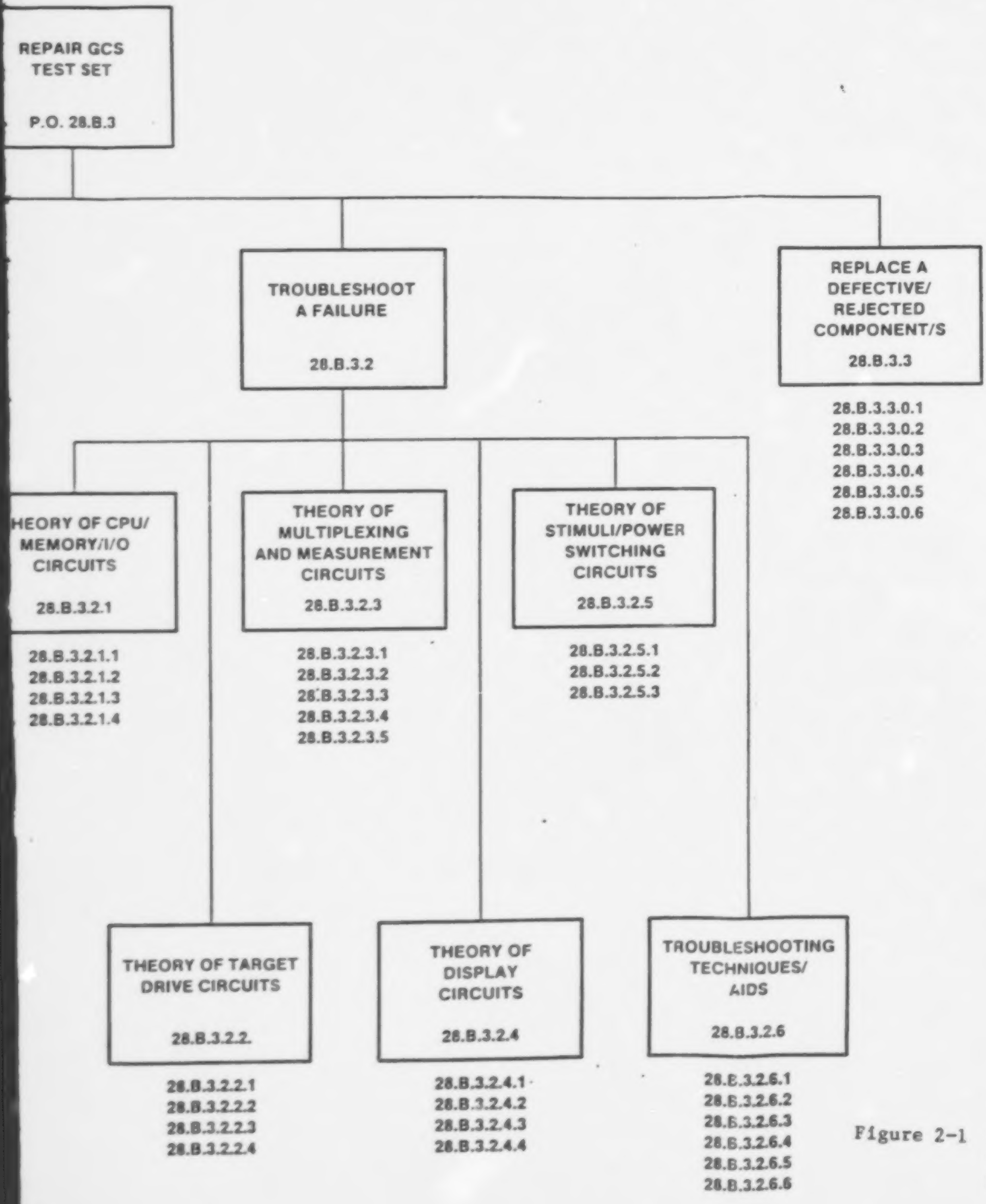

Figure 2-1 Sample Task Analysis Training Objective Hierarchy

2.3.2.4 Media Analysis Data

The raw data needed to perform the Media Analysis is contained in the Performance Statement (also referred to as the Task Statement) of each objective, no matter whether it is terminal or enabling. Therefore, the Task Analysis Report Summary, Table 3-1, columns 2 and 3, only display the performance or task statement portion of the original objective.

2.3.2.5. Learning Category and Sub-Category

When the performance or task statement has been determined, it must be analyzed to determine its "learning category". Instructional technologists often divide learning into four basic skill types: physical, mental, informational, and attitudinal.

In our slected media analysis methodology, objectives are categorized into these four areas, and then further sub-divided into eleven (11) sub-categories of learning. These sub-categories are: detecting, making decisions, recalling bodies of knowledge, performing gross motor skills, steering and guiding continuous movement, positioning movement and recalling procedures, voice communicating, and attitude learning. A fuller and more descriptive listing of the categories of learning and the eleven sub-categories is contained on Table 2-1, (see following pages) extracted from the "Interservices Procedures for Instructional Systems Development, Phase III, Develop", pages 13 through 16.

2.3.2.6 Selecting the Training Media

The final step in making a selection of training media is to take the learning sub-category data of the identified objectives and apply this information to a Media Selection Decision Matrix. In the selected Florida State University methodology, a Decision Matrix has been developed and provided for each of the eleven sub-categories of learning. A sample of one of the original matrices is shown on the following page, as Table 2-2. Because this study is limited to examining the effectiveness of only computer-aided learning media on RAMP equipment, the Florida State decision matrices used for this media analysis (section 4) have been simplified. Because the alternative forms of media (see Table 2-2 on the following page) are not the object of investigations, all forms of media except CAL have been dropped from the RAMP Media Selection Decision Matrices, Table 4-1 through 4-6. Additionally, several new criteria have been added to the administrative questions included on each table. These questions reflect the concern for both the transportability and the potential remote site locations of CAL systems expressed in "Maintenance 2000".

The decision matrices used in developing our final conclusions are six in number, one for each of the six learning sub-categories identified in the RAMP Task Analysis Report Summary, Table 3-1. Each of the six decision matrices shows that computer-aided learning generally is a viable medium for teaching for these types of learning requirements. Each Decision Matrix has been completed to provide a RAMP project-specific focus to the media analysis process. This last step in the analysis focus to the media analysis process. This last step in the analysis confirms that computer-aided learning systems are capable of delivering instruction of the great majority of RAMP training objectives.

Table 2-1 Description of Training Task Categories

LEARNING CATEGORY	SUB-CATEGORY	ACTION VERBS	BEHAVIORAL ATTRIBUTES	EXAMPLES
I. Mental Skill	1. Rule Learning & Using	Apply Conclude Deduce Predict Propose Select Specify Solve Determine Repair	1. Choosing a course of action based on applying known rules. 2. Frequently involves "If...then" situations. 3. The rules are not questioned, the decision focuses on whether the correct rule is being applied.	1. Apply the "rules of the road." 2. Solve mathematical equations (both choosing correct equations and the mechanics of solving the equation). 3. Carrying out military protocol. 4. Selection of proper fire extinguisher for different types of fires. 5. Using correct grammar in novel situations covered by rules.
	2. Classifying-Recognizing Patterns	Classify Differentiate Identify Recognize	1. Pattern recognition approach to identification--not problem solving. 2. Classification by non-verbal characteristics. 3. Status determination--ready to start. 4. Object to be classified can be viewed from many perspectives or in many forms.	1. Classify a sonar target as "sub" or "non-sub." 2. Visual classification of flying aircraft as "friend" or "enemy" or as an "F-4." 3. Determining that an identified noise is a wheel bearing failure not a water pump failure by rating the quality of the noise--not by the problem solving approach.
	3. Identifying Symbols	Identify Read Transcribe	1. Involves the recognition of symbols such as in codes, diagrams, schematics, etc. 2. Symbols to be identified typically are of low meaningfulness to untrained persons. 3. Identification, not interpretation, is emphasized.	1. Reading electronic symbols on a schematic drawing. 2. Identifying map symbols. 3. Reading and transcribing symbols on a tactical status board. 4. Identifying symbols on a weather map.
	4. Detecting	Detect Distinguish Monitor	1. Vigilance--detect a few cues embedded in a large block of time. 2. Low threshold cues; signal to noise ratio may be very low; early awareness of small cues. 3. Scan for a wide range of cues for a given "target" and for different types of "targets."	1. Early sonar detection of a submarine target. 2. Visually detecting the periscope of a snorkeling submarine during daytime. 3. Detect, through a slight change in sound, a bearing starting to burn out in a power generator.
	5. Making Decisions	Choose Diagnose Develop Evaluate Forecast Formulate Organize Select Repair	1. Choosing a course of action when alternatives are unspecified or unknown. 2. A successful course of action is not readily apparent. 3. The penalties for unsuccessful courses of action are not readily apparent. 4. The relative value of possible decisions must be considered--including possible trade-offs.	1. Choosing torpedo settings during a torpedo attack. 2. Threat evaluation and weapon assignment. 3. Choice of tactics in combat--wide range of options. 4. Choosing a diagnostic strategy in dealing with a malfunction in a complex piece of equipment. 5. Choosing to abort or commit oneself to land upon reaching the critical point in the glidepath.
II. Information	6. Recalling Bodies of Knowledge	List Define State Recite Select	1. Concerns verbal or symbolic learning. 2. Concerns acquisition and long-term maintenance of knowledge so that it can be recalled.	1. Recalling equipment nomenclature or functions. 2. Recalling system functions, such as the complex relations between system input and output. 3. Recalling physical laws, such as Ohm's Law. 4. Recalling specific radio frequencies and other discrete facts.

Table 2-1 Description of Training Task Categories (cont'd)

LEARNING CATEGORY	SUB-CATEGORY	ACTION VERBS	BEHAVIORAL ATTRIBUTES	EXAMPLES
III. Physical Skill	7. Perform Gross Motor Skills	Cut Draft Draw March Mix Run Sew Sharpen Splice Swim Weld Write	1. Perceptual motor behavior; emphasis on motor. Premium on manual dexterity, occasionally strength and endurance. 2. Repetitive mechanical skills. 3. Standardized behavior, little room for variation or innovation. 4. Automatic behavior--low level of attention is required in skilled operator. Kinesthetic cues dominate control of behavior. 5. Fatigue or boredom may become a factor when skill is performed over an extended period of time or at a rapid rate. 6. Fine tolerances. 7. Often a component of a larger task.	1. Use of hand tools such as hammer, saw, wrench, or power tools such as lathes or grinders. 2. Running a drill press in an assembly line. 3. Loading ammunition into artillery pieces of 5" guns. 4. Drafting--use of drafting instruments. 5. Painting--house painting or preserving ship hull, etc. 6. Marching--close order drill.
	8. Steering and Guiding Continuous Movement	Control Guide Maneuver Regulate Steer Track	1. Tracking, dynamic control--a perceptual motor skill involving continuous pursuit of a target or keeping dials at a certain reading such as maintaining constant turn rates, etc. 2. Compensatory movements based on feedback from displays. 3. Skill in tracking requires smooth muscle coordination patterns--lack of overcontrol. 4. Involves estimating changes in positions, velocities, accelerations, etc. 5. Involves knowledge of display-control relationships.	1. Submarine bow and stern planes operators maintaining a constant course, or making changes in course or depth. 2. Tank driver following a road. 3. Sonar operator keeping the cursor on a sonar target. 4. Air-to-air gunnery--target tracking. 5. Aircraft piloting such as visually following a ground path. 6. Helmsman holding a course with gyro or magnetic compass.
	9. Positioning Movement & Recalling Procedures	Activate Adjust Align Assemble Calibrate Disassemble Inspect Operate Service	1. Concerns the chaining or sequencing of events. 2. Includes both the cognitive and motor aspects of equipment set-up and operating procedures. 3. Procedural check lists are frequently used as job aids.	1. Recalling equipment assembly and disassembling procedures. 2. Recalling the operation and check out procedures for a piece of equipment (cockpit check lists). 3. Following equipment turn-on procedures--emphasis on motor behavior.
	10. Voice Communicating	Advise Answer Communicate Converse Direct Express Instruct Interview Listen Order Report Sing Speak	1. Speaking and listening in specialized languages. 2. Often involves the use of a specific message model. Standard vocabulary and format. 3. Also concerns clarity of voice, enunciation and speed. 4. Timing of verbalization if usually critical--when to pass information. 5. Typically characterized by redundancy in terms of information content. 6. Involves extensive use of previously overlearned verbal skills, or overcoming overlearned interfering patterns. 7. Tasks may be difficult due to background noise.	1. Officer giving oral orders and receiving reports. 2. Sonar operator passing oral information over communications net. 3. Instructions by ground control operator to pilot in landing aircraft.

Table 2-1 Description of Training Task Categories (cont'd)

LEARNING CATEGORY	SUB-CATEGORY	ACTION VERBS	BEHAVIORAL ATTRIBUTES	EXAMPLES
IV. Attitude	11. Attitude Learning	Abide Accept Comply Choose Select	1. Concerns exhibiting a pattern of behavior consistent with an attitude or value. 2. Concerns willingness to perform according to a standard as opposed to skill to perform according to that standard. (NOTE: A person can have a high level of skill but choose not to perform in a skillful manner.) 3. Concerns integrating or organizing a value or attitude into a pattern of behavior.	1. Complying with known safety standards while performing a maintenance procedure on a high voltage supply in a radar set. 2. Conforming to the standard of keeping one's bunk area neat and clean when the opportunity exists to do otherwise. 3. Abiding by security regulations when handling classified information. 4. Accepting the need to take risks when necessary to protect the lives of teammates. 5. Complying with a request to repair a malfunctioning radio circuit with greater than normal speed when a quick response is required.

Table 2-2 Sample Media Selection Decision Matrix
Sub-Category 2 Classifying

Criteria for Selecting Instructional Delivery Systems	Directions: To choose a delivery system: 1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met. 2. Select the delivery systems (columns) that have an "X" in each row designated by a "√". These are the candidate delivery systems.	Alternative Instructional Delivery Systems										
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm					Delivery Approaches NOT Permitting Complete Application of Learning Guideliens ans Algorithm					
		CAI w/Adjunct Equipment and Materials	Study Card Sets	Microfiche	Teaching Machine - Branching	Simulator with Adjunct Displays or Instructor	Slide Sets with Instructor	Traditional Classroom with AV Materials	Audio Recorders - Disc or Tape	Specimen Set	Sound Slide/Film Strip Program	
Stimulus Criteria												
● Visual Form												
Alphanumeric		X	X	X	X	X	X	X			X	
Pictorial, Plane		X	X	X	X		X	X			X	
Line Construction, Plane		X	X	X	X		X	X			X	
Object, Solid						X				X		
Environment						X						
● Visual Movement												
Still		X	X	X	X		X	X		X	X	
Limited		X			X			X			X	
Full						X		X				
● Scale												
Exact Scale						X				X		
● Audio												
Voice Sound Range		X			X	X	X	X	X		X	
Full Sound Range						X			X			
Ambient Sounds						X						
Other Tactile Cues						X				X		
Internal Stimulus Motion Cues						X						
External Stimulus Motion Cues						X						
Training Setting Criteria												
● Individual Trainee at a Fixed Location		X	X	X	X	X	X		X	X	X	
● Individual Trainee with Independent Instruction at Any Location			X	X					X		X	
● Small Group							X	X	X		X	
● Large Group at Single Location							X	X	X		X	
Administrative Criteria												
● Site of Courseware and Special Hardware Development												
Local			X	X	X		X	X	X	X	X	
Cei		X	X	X	X	X	X	X	X	X	X	
● Magnitude of Acquisition Cost												
Low			X	X			X	X	X	X	X	
High		X			X	X						

Source:

3. RAMP TASK ANALYSIS REPORT

The RAMP Task Analysis Report (TAR) contains a listing of the 373 training objectives developed on RAMP radar, displays and related test and diagnostic equipment. The listing is provided in this Study as the following twenty-three (23) page table entitled "RAMP Task Analysis Report Summary, Table 3-1". The following section, 3.1, explains how the information on Table 3-1 is organized.

3.1 Organization of the TAR Summary, Table 3-1

Data in the TAR Summary is arranged in order by maintenance level, terminal objective, RAMP system and sub-system, and finally by task statement and learning category.

3.1.1 Maintenance Levels

The data on the Table 3-1 is arranged first by the appropriate level of RAMP maintenance. This is indicated at the top of the first page of the TAR Summary Table by the circled number "1". The first five (5) pages of TAR Summary contain the Level I objectives, and the following three (3) pages feature the listing of Level II objectives.

The RAMP equipment maintenance concept defines Level I maintenance as fault isolation and replacement of the lowest replaceable unit (LRU) or module (LRM) in the field. Level II maintenance involves the repair of the LRU assembly or board on special test equipment in a centrally located maintenance facility.

Because the task analysis data on the RAMP Displays is still under development, available data is limited to the Troubleshooting and Repair objectives at Level II maintenance. These objectives are listed on the last four (4) pages of Table 3-1.

3.1.2 Terminal Objective

Within each maintenance level, we have sub-divided our objectives by the type of terminal objective (see section 2.3.2.3), as determined by the action verb(s) phrase of that objective. Thus, all Level I objectives are listed under headings which begin with "operate", "perform preventive maintenance", "troubleshoot and repair" and "exercise safety precautions". The Terminal objective on the first page of Table 3-1 is indicated by the circled number "2".

3.1.3 RAMP Equipment System and Sub-System

The first column on each page of the TAR Summary is entitled "RAMP Sub-system". Under this heading, the reader will find the name of a major item of RAMP equipment or a sub-system of that major item. This information is indicated by the circled number "3" on the first page of the TAR Summary Table.

3.1.4 Task Statement's Learning Requirement and Content

The second and third column of the TAR Summary, Table 3-1, contains the 373 RAMP training objectives, which are listed in an abbreviated form, consisting of the performance or task statement portion of the objective.

Note that the task statement is divided into two parts. The first column contains the "learning requirement", the second column the "content" statement. This distinction is key to differentiating what the trainee will DO from what the trainee will LEARN. Highlighting the learning requirements of these objectives provides the Media Analyst with an at-a-glance picture of what types of learning behaviors will be required of the trainees. This data is key to determining learning categories.

The location of the Task Statement of the TAR Summary Table is indicated on the first page of the Table by the circled number "4". The circled number "5" indicates the location of the "Learning Requirement" column, and the circled number "6" the location of the "Content" column.

3.1.5 Learning Category and Sub-Category

The fourth and fifth columns on each page of the TAR Summary table depict learning category and sub-category information. These are so indicated by the circled numbers "7" and "8". Learning Categories are more fully explained in section 2.2.2.5.

3.1.6 Summary of Task Analysis Report Data on Learning Categories

Learning category data on the 373 RAMP training objectives is summarized on the following page, Table 3-2. All tasks fell into either informational, physical, or mental task areas. No attitudinal learning requirements were identified.

Table 3-1 Task Analysis Report Summary

Level I Maintenance

① LEVEL I MAINTENANCE

TERMINAL OBJ: OPERATE ②

SUBSYSTEM ③	TASK STATEMENT ④ LEARNING REQUIREMENT ⑤	CONTENT ⑥	LEARNING CATEGORY ⑦	SUB-CATEGORY ⑧
Primary Surveillance Radar	State	Purpose	(II) Info	(6) Recalling
	State	Specifications	(II) Info	(6) Recalling
	Interpret	Block Diagram	(I) Mental	(1) Rule Using
	Identify	LRUs	(I) Mental	(2) Recognizing
	Identify	Controls/ Indicators	(I) Mental	(2) Classifying
	State	Functions	(II) Info	(5) Recalling
	Describe	Modes of Operation	(II) Info	(6) Recalling
	Operate	PSR TX	(III) Physical	(9) Recalling
Secondary Surveillance Radar	State	Purpose	(II) Info	(6) Recalling
	State	Specifications	(II) Info	(6) Recalling
	Interpret	Block Diagram	(I) Mental	(1) Rule Using
	Identify	LRUs	(I) Mental	(2) Recognizing
	Identify	Controls/ Indicators	(I) Mental	(2) Classifying
	State	Functions	(II) Info	(6) Recalling
	Describe	Modes of Operation	(II) Info	(6) Recalling
	Operate	RF Changeover	(III) Physical	(9) Recalling
	Operate	SSR Interrogator	(III) Physical	(9) Recalling
	Operate	SSR Plot Extractor	(III) Physical	(9) Recalling
Radar Data Transfer	State	Purpose	(II) Info	(6) Recalling
	State	Specifications	(II) Info	(6) Recalling
	Interpret	Block Diagram	(I) Mental	(1) Rule Using
	Describe	Configurations	(II) Info	(6) Recalling
	Identify	LRUs	(I) Mental	(2) Recognizing
	Identify	Controls/ Indicators	(I) Mental	(2) Classifying
	State	Functions	(II) Info	(6) Recalling
	Describe	Modes of Operation	(II) Info	(6) Recalling
	Operate	RDT subsystem	(III) Physical	(9) Recalling

TERMINAL OBJ: OPERATE

SUBSYSTEM	TASK STATEMENT LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Maintenance Data Transfer	State	Purpose	(II) Info	(6) Recalling
	State	Specifications	(II) Info	(6) Recalling
	Interpret	Block Diagrams	(I) Mental	(1) Rule Using
	Describe	Configurations	(II) Info	(6) Recalling
	Identify	LRUs	(I) Mental	(2) Recognizing
	Identify	Controls/ Indicators	(I) Mental	(2) Classifying
	State	Functions	(II) Info	(6) Recalling
	Describe	Modes of Operation	(II) Info	(6) Recalling
	State	Functions	(II) Info	(6) Recalling
	Operate	MCU	(III) Physical	(9) Recalling
	Operate	MECC	(III) Physical	(9) Recalling
	Operate	RMD	(III) Physical	(9) Recalling
	Operate	Portable VDU	(III) Physical	(9) Recalling
Antenna Pedestal Group	State	Purpose	(II) Info	(6) Recalling
	State	Specifications	(II) Info	(6) Recalling
	Interpret	Block Diagrams	(I) Mental	(1) Rule Using
	Identify	LRUs	(I) Mental	(2) Recognizing
	Identify	Controls/ Indicators	(I) Mental	(2) Classifying
	State	Functions	(II) Info	(6) Recalling
	Operate	Antenna Pedestal Controller	(III) Physical	(9) Recalling
	Operate	ADU	(III) Physical	(9) Recalling

Table 3-1 Task Analysis Report Summary

Level I Maintenance (Cont'd)

TERMINAL OBJ: OPERATE (CONTINUED)

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Uninterruptable Power Supply	State	Purpose	(II) Info	(6) Recalling
	State	Specifications	(II) Info	(6) Recalling
	Interpret	Block Diagram	(I) Mental	(1) Rule Using
	Identify	LRU	(I) Mental	(2) Recognizing
	Identify	Controls/ Indicators	(I) Mental	(2) Classifying
	State	Functions	(II) Info	(6) Recalling
	Describe	Modes nf Operation	(II) Info	(6) Recalling
	Operate	IPU	(III) Physical	(9) Recalling
	Operate	SUPU	(III) Physical	(9) Recalling

TERMINAL OBJ: PERFORM PREVENTATIVE MAINTENANCE CHECKS & ADJUSTMENTS

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Primary Surveillance Radar	State	Requirements	(II) Info	(6) Recalling
	Test	PSR TX	(III) Physical	(9) Positioning
	Adjust	PSR TX	(III) Physical	(9) Positioning
	Test	PSR REX	(III) Physical	(9) Positioning
	Perform	Alignments	(III) Physical	(9) Positioning
Secondary Surveillance Radar	State	Requirements	(II) Info	(6) Recalling
	Perform	Alignment/ Interrogator	(III) Physical	(9) Positioning
	Perform	Alignment/ Plot Extractor	(III) Physical	(9) Positioning
Radar Data Transfer	State	Requirements	(II) Info	(6) Recalling
	Describe	Procedures	(II) Info	(6) Recalling
Maintenance Data Transfer	State	Requirements	(II) Info	(6) Recalling
	Describe	Procedures	(II) Info	(6) Recalling
Antenna Pedestal Group	State	Requirements	(II) Info	(6) Recalling
	Describe	Preventative Maintenance	(II) Info	(6) Recalling
	Describe	Procedures	(II) Info	(6) Recalling
Uninterruptable Power Supply	State	Requirements	(II) Info	(6) Recalling
	Test	IPU	(III) Physical	(9) Positioning
	Adjust	IPU	(III) Physical	(9) Positioning
	Test	SUPU	(III) Physical	(9) Positioning
	Perform	Alignments	(III) Physical	(9) Positioning

TERMINAL OBJ: TROUBLESHOOT AND REPAIR

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Primary Surviellance Radar	Describe	Theory of Operation (Transmitter)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Receiver Exciter)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Signal Data Processor)	(II) Info	(6) Recalling
	Describe	Theory of Operation (BITE Processor)	(II) Info	(6) Recalling
	Describe	Power Distribution	(II) Info	(6) Recalling
	Trace	Data Signals/ Command Control Signals	(I) Mental	(3) Identifying
	Describe	BITE and Diagnostic Capabilities	(II) Info	(6) Recalling
	Troubleshoot	PSR using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	PSR using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Locate	LRMs	(I) Mental	(2) Recognizing
	Describe	Repair Procedures	(II) Info	(6) Recalling

Table 3-1 Task Analysis Report Summary

Level I Maintenance (Cont'd)

TERMINAL OBJ: TROUBLESHOOT AND REPAIR - (CONTINUED)

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Secondary Surveillance Radar	Describe	Theory of Operation (Changeover Unit)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Interrogator)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Plot Extractor)	(II) Info	(6) Recalling
	Describe	Power Distribution	(II) Info	(6) Recalling
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	BITE and Diagnostic Capabilities	(II) Info	(6) Recalling
	Troubleshoot	SSR using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	SSR using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Locate	LRMs	(I) Mental	(2) Recognizing
	Describe	Repair Procedures	(II) Info	(6) Recalling
Radar Data Transfer	Describe	Theory of Operation (CFU)	(II) Info	(6) Recalling
	Describe	Theory of Operation (CP)	(II) Info	(6) Recalling
	Describe	Theory of Operation (DCE)	(II) Info	(6) Recalling
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Troubleshoot	RDT using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	RDT Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Locate	LRMs	(I) Mental	(2) Recognizing
	Describe	Repair Procedures	(II) Info	(6) Recalling
Maintenance Data Transfer	Describe	Theory of Operation (Status & Control Processor)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Auxiliary Status Processor)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Real Time Data Processor)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Data Communications Equipment	(II) Info	(6) Recalling
	Describe	Theory of Operation (Maintenance Status & Control Console)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Radar Maintenance Display)	(II) Info	(6) Recalling
	Describe	Power Distribution	(II) Info	(6) Recalling
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	BITE and Diagnostic Capabilities	(II) Info	(6) Recalling
	Troubleshoot	MDT using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	MDT using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Locate	LRMs	(I) Mental	(2) Recognizing
	Describe	Repair Procedures	(II) Info	(6) Recalling

Table 3-1 Task Analysis Report Summary

Level I Maintenance (Cont'd)

TERMINAL OBJ: TROUBLESHOOT AND REPAIR - (CONTINUED)

SUBSYSTEM	TASK STATEMENT		LEARNING CATEGORY	SUB-CATEGORY
	LEARNING REQUIREMENT	CONTENT		
Pedestal Drive Assy	Describe	Theory of Operation (Lubrication System)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Rotary Joint)	(II) Info	(6) Recalling
	Describe	Theory of Operation (APG Assy)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Controller/ Starter)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Encoder)	(II) Info	(6) Recalling
	Describe	Theory of Operation (AGU)	(II) Info	(6) Recalling
	Describe	Theory of Operation (PSR Antenna)	(II) Info	(6) Recalling
	Describe	Theory of Operation (SSR Antenna)	(II) Info	(6) Recalling
	Describe Trace	Power Distribution Data Signals/ Command & Control Signals	(II) Info (I) Mental	(6) Recalling (3) Identifying
	Describe	BITE Diagnostic Capabilities	(II) Info	(6) Recalling
	Troubleshoot	PDA Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision
Making	Troubleshoot	PDA Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision
Making	Locate Describe	LRUs Repair Procedures	(I) Mental (II) Info	(2) Recognizing (6) Recalling
Uninterruptable Power Supply (UPS)	Describe	Theory of Operation (IPU)	(II) Info	(6) Recalling
	Describe	Theory of Operation (SUPU)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Power Distribution)	(II) Info	(6) Recalling
	Describe	Theory of Operation (Command & Control)	(II) Info	(6) Recalling
	Trace	Data Signals/ Command & Control Signals)	(I) Mental	(3) Identifying
	Describe	BITE & Diagnostic Capabilities	(II) Info	(6) Recalling
	Troubleshoot	UPS using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision
Making	Troubleshoot	UPS using Manual Procedures	(III) Physical	(9) Positioning
	Locate Describe	LRUs Repair Procedures	(I) Mental (II) Info	(2) Recognizing (6) Recalling

Table 3-1 Task Analysis Report Summary

Level I Maintenance (Cont'd)

TERMINAL OBJ: EXERCISE SAFETY PRECAUTIONS TO AVOID INJURY

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Primary Surveillance Radar	State	Safety Precautions (Mechanical)	(II) Info	(6) Recalling
	State	Safety Precautions (Electrical)	(II) Info	(6) Recalling
Secondary Surveillance Radar	State	Safety Precautions (Mechanical)	(II) Info	(6) Recalling
	State	Safety Precautions (Electrical)	(II) Info	(6) Recalling
Radar Data Transfer	State	Safety Precautions (Mechanical)	(II) Info	(6) Recalling
	State	Safety Precautions (Electrical)	(II) Info	(6) Recalling
Maintenance Data Transfer	State	Safety Precautions (Mechanical)	(II) Info	(6) Recalling
	State	Safety Precautions	(II) Info	(6) Recalling
Antenna Pedestal Equipment	State	Safety Precautions (Mechanical)	(II) Info	(6) Recalling
	State	Safety Precautions (Electrical)	(II) Info	(6) Recalling
Microwave Component	State	Safety Precautions (Mechanical)	(II) Info	(6) Recalling
	State	Safety Precautions (Electrical)	(II) Info	(6) Recalling
Uninterruptable Power Supply	State	Safety Precautions (Mechanical)	(II) Info	(6) Recalling
	State	Safety Precautions (Electrical)	(II) Info	(6) Recalling

TERMINAL OBJ: EXERCISE SAFETY PRECAUTIONS TO PREVENT DAMAGE

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Primary Surveillance Radar	State	Precautions (While Operating)	(II) Info	(6) Recalling
	State	Precautions (While Maintaining)	(II) Info	(6) Recalling
Secondary Surveillance Radar	State	Precautions (While Operating)	(II) Info	(6) Recalling
	State	Precautions (While Maintaining)	(II) Info	(6) Recalling
Radar Data Transfer	State	Precautions (While Operating)	(II) Info	(6) Recalling
	State	Precautions (While Maintaining)	(II) Info	(6) Recalling
Maintenance Data Transfer	State	Precautions (While Operating)	(II) Info	(6) Recalling
	State	Precautions (While Maintaining)	(II) Info	(6) Recalling
Antenna Pedestal Group	State	Precautions (While Operating)	(II) Info	(6) Recalling
	State	Precautions (While Maintaining)	(II) Info	(6) Recalling

Table 3-1 Task Analysis Report Summary

Level II Maintenance

TERMINAL OBJ: OPERATE

SUBSYSTEM	TASK STATEMENT		LEARNING CATEGORY	SUB-CATEGORY
	LEARNING REQUIREMENT	CONTENT		
Power Supply Test Set	State	Purpose	(II) Info	(6) Recalling
	State	Specification	(II) Info	(6) Recalling
	Interpret	Block Diagram	(I) Mental	(1) Rule Using
	Identify	LRU	(I) Mental	(2) Recognizing
	Identify	Controls/ Indicators	(I) Mental	(2) Classifying
	State	Functions	(II) Info	(6) Recalling
	Describe	Modes of Operation	(II) Info	(6) Recalling
	Perform	Diagnostic Functions	(III) Physical	(9) Recalling
	Operate	Power Supply Test Set	(III) Physical	(9) Recalling
HP 3065 Test Set	State	Purpose	(II) Info	(6) Recalling
	State	Specifications	(II) Info	(6) Recalling
	Interpret	Block Diagram	(I) Mental	(1) Rule Using
	Identify	LRUs	(I) Mental	(2) Recognizing
	Identify	Controls/ Indicators	(I) Mental	(2) Classifying
	State	Functions	(II) Info	(6) Recalling
	Describe	Modes of Operation	(II) Info	(6) Recalling
	Perform	Self Test Procedure	(III) Physical	(9) Recalling
	Operate	HP 3065 Test Set	(III) Physical	(9) Recalling
RF/IF Test Set	State	Purpose	(II) Info	(6) Recalling
	State	Specifications	(II) Info	(6) Recalling
	Interpret	Block Diagram	(I) Mental	(1) Rule Using
	Identify	LRUs	(I) Mental	(2) Recognizing
	Identify	Controls/ Indicators	(I) Mental	(2) Classifying
	State	Functions	(II) Info	(6) Recalling
	Describe	Modes of Operation	(II) Info	(6) Recalling
	Operate	RF/IF Test Set	(III) Physical	(9) Recalling

TERMINAL OBJ: PERFORM ALL PREVENTATIVE MAINTENANCE CHECKS AND ADJUSTMENTS

SUBSYSTEM	TASK STATEMENT		LEARNING CATEGORY	SUB-CATEGORY
	LEARNING REQUIREMENT	CONTENT		
Power Supply Test Set	State	Maintenance Requirements	(II) Info	(6) Recalling
	Perform	Diagnostic Procedures	(III) Physical	(9) Positioning
	Align	Power Supply Test Set	(III) Physical	(9) Positioning
HP 3065 Test Set	State	Maintenance Requirements	(II) Info	(6) Recalling
	Test	HP 3065 Test Set	(III) Physical	(9) Positioning
	Adjust	HP 3065 Test Set	(III) Physical	(9) Positioning
RF/IF Test Set	State	Maintenance Requirements	(II) Info	(6) Recalling
	Perform	Alignment Procedures	(III) Physical	(9) Positioning
	Perform	Test Set Procedures	(III) Physical	(9) Positioning

Table 3-1 Task Analysis Report Summary

Level II Maintenance (Cont'd)

TERMINAL OBJ: TROUBLESHOOT AND REPAIR: IDENTIFY THE FAULT

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Power Supply Test Set	Describe	Theory of Operation	(II) Info	(6) Recalling
	Describe	Power Distribution	(II) Info	(6) Recalling
	Trace	Data Signals/ Command Control Signals	(I) Mental	(3) Identifying
	Describe	Diagnostic Capabilities	(II) Info	(6) Recalling
	Troubleshoot	Power Supply Test Set Self Test	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Describe	Repair Procedures	(II) Info	(6) Recalling
HP 3065 Test Set	Describe	Theory of Operation	(II) Info	(6) Recalling
	Describe	Power Distribution	(II) Info	(6) Recalling
	Trace	Data Signals/ Command Control Signals	(I) Mental	(3) Identifying
	Describe	Diagnostic Capabilities	(II) Info	(6) Recalling
	Troubleshoot	HP 3065 Test Set Self Test	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Locate	LRUs	(I) Mental	(2) Recognizing
	Describe	Repair Procedures	(II) Info	(6) Recalling
RF/IF Test Set	Describe	Theory of Operation	(II) Info	(6) Recalling
	Describe	Power Distribution	(II) Info	(6) Recalling
	Trace	Data Signals/ Command Control Signals	(I) Mental	(3) Identifying
	Describe	Diagnostic Capabilities	(II) Info	(6) Recalling
	Troubleshoot	RF/IF Test Set - Self Test	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	RF/IF Test Set Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Locate	LRUs	(I) Mental	(2) Recognizing
	Describe	Repair Procedures	(II) Info	(6) Recalling

Table 3-1 Task Analysis Report Summary

Level II Maintenance (Cont'd)

TERMINAL OBJ: OPERATE TROUBLESHOOT THE FAILED LRM
REPAIR THE FAILED LRM
RETEST THE LRM

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Power Supply Test Set	Identify	LRM	(I) Mental	(2) Recognizing
	State	Function	(II) Info	(6) Recalling
	Identify	Test Requirement	(I) Mental	(5) Make Decision
	Prepare	Power Supply Test Set	(III) Physical	(9) Positioning
	Troubleshoot	LRM	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Interpret	Automatic Test Program Diagnostics	(I) Mental	(1) Rule Using
	Identify	Failed Component	(I) Mental	(2) Recognizing
	Repair	LRM	(III) Physical	(9) Positioning
	Retest	LRM	(III) Physical	(9) Positioning
HP 3065 Test Set	Identify	LRM	(I) Mental	(2) Recognizing
	State	Function	(II) Info	(6) Recalling
	Identify	Test Requirement	(I) Mental	(5) Make Decision
	Prepare	HP 3065 Test Set	(III) Physical	(9) Positioning
	Troubleshoot	LRM	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Interpret	Automatic Test Program Diagnostics	(I) Mental	(1) Rule Using
	Identify	Failed component	(I) Mental	(2) Recognizing
	Repair	LRM	(III) Physical	(9) Positioning
	Retest	LRM	(III) Physical	(9) Positioning

TERMINAL OBJ: EXERCISE SAFETY PRECAUTIONS TO AVOID INJURY

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
RF/IF Test Set	Identify	LRM	(I) Mental	(2) Recognizing
	State	Function	(II) Info	(6) Recalling
	Identify	Requirements	(I) Mental	(5) Make Decision
	Prepare	RF/IF Test Set	(III) Physical	(9) Positioning
	Troubleshoot	LRM	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Interpret	Automatic Test Program Diagnostics	(I) Mental	(I) Rule Using
	Identify	Failed component	(I) Mental	(2) Recognizing
	Repair	LRM	(III) Physical	(9) Positioning
	Retest	LRM	(III) Physical	(9) Positioning
Power Supply Test Set	State	Precautions - Mechanical Portions	(II) Info	(6) Recalling
	State	Precautions - Electrical Equipment	(II) Info	(6) Recalling
HP 3065 Test Set	State	Precautions - Mechanical Portions	(II) Info	(6) Recalling
	State	Precautions - Electrical Equipment	(II) Info	(6) Recalling
RF/IF Test Set	State	Precautions - Mechanical Portions	(II) Info	(6) Recalling
	State	Precautions - Electrical Equipment	(II) Info	(6) Recalling

Table 3-1 Task Analysis Report Summary

Level II Maintenance (Cont'd)

TERMINAL OBJ: EXERCISE SAFETY PRECAUTIONS TO AVOID DAMAGE

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Power Supply Test Set	State	Precautions - While Operating	(II) Info	
	State	Precautions - While Maintaining	(II) Info	(6) Recalling
HP 3065 Test Set	State	Precautions - While Operating	(II) Info	(6) Recalling
	State	Precautions - While Maintaining	(II) Info	(6) Recalling
RF/IF Test Set	State	Precautions - While Operating	(II) Info	(6) Recalling
	State	Precautions - While Maintaining	(II) Info	(6) Recalling

Display

TERMINAL OBJ: TROUBLESHOOT AND REPAIR

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Radar Data Processing System	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
Processors	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
Operational Software Adaptation Facility	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling

Table 3-1 Task Analysis Report Summary

Display (Cont'd)

TERMINAL OBJ: TROUBLESHOOT AND REPAIR

SUBSYSTEM	TASK STATEMENT LEARNING REQUIREMENT	TASK STATEMENT CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Data Recording Facility	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
Lan Trans-ceiver	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
Tape Drive	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling

TERMINAL OBJ: TROUBLESHOOT AND REPAIR

SUBSYSTEM	TASK STATEMENT LEARNING REQUIREMENT	TASK STATEMENT CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Printer	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
VDU	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling

Table 3-1 Task Analysis Report Summary

Display (Cont'd)

TERMINAL OBJ: TROUBLESHOOT AND REPAIR (CONTINUED)

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Maintenance Display	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling

TERMINAL OBJ: TROUBLESHOOT AND REPAIR

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Radar Simulator	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
Maintenance Control Position	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
Database Management System	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling

Table 3-1 Task Analysis Report Summary

Display (Cont'd)

TERMINAL OBJ: TROUBLESHOOT AND REPAIR

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Disk Drives	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
Telephone Dial-Up Unit	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling

TERMINAL OBJ: TROUBLESHOOT AND REPAIR

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Comm Simulator	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
Uninterruptable Power Supply	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling

Table 3-1 Task Analysis Report Summary

Display (Cont'd)

TERMINAL OBJ: TROUBLESHOOT AND REPAIR

	TASK STATEMENT			
SUBSYSTEM	LEARNING REQUIREMENT	CONTENT	LEARNING CATEGORY	SUB-CATEGORY
Joint Enroute Terminal System	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling
Disk/Tape Controller	Describe	Theory of Operation	(II) Info	(6) Recalling
	Troubleshoot	Using BITE	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Troubleshoot	Using Manual Procedures	(III) Physical & (I) Mental	(9/5) Positioning Recall Decision Making
	Know	Locations of LRMs	(I) Mental	(2) Recognizing
	Trace	Data Signals/ Command & Control Signals	(I) Mental	(3) Identifying
	Describe	Repair Procedures	(II) Info	(6) Recalling

Table 3-2 RAMP Task Analysis Report Learning Category Summary Sheet

I. MENTAL	Rule Using	Classify/ Recognize	Identify	Make Decisions	
LEVEL I:	6	18	6	0	
LEVEL II:	6	14	3	1	
DISPLAY:	0	18	18	0	
	12	50	27	1	
					TOTAL: 90

II. INFORMATION	Recall	
LEVEL I:	103	
LEVEL II:	42	
DISPLAY:	36	
		TOTAL: 181

III. PHYSICAL SKILLS	Positioning/Recall	
LEVEL I:	35	
LEVEL II:	31	
DISPLAY:	36	
		TOTAL: 102

IV. ATTITUDE: None

CATEGORY SUMMARY:

I. MENTAL TASKS	90	24.2%	
II. INFORMATION TASKS	181	48.5%	
III. PHYSICAL TASKS	102	27.3%	
	373	100.0%	
			TOTAL: 373

STEP II

REPORT OF RAMP MAINTENANCE TRAINING MEDIA ANALYSIS: AFFIRMATION OF THE VIABILITY OF COMPUTER ASSISTED LEARNING (CAL) AS A REFRESHER TRAINING MEDIUM FOR AIR TRAFFIC CONTROL MAINTENANCE TECHNICIANS

4. RAMP MAINTENANCE TRAINING MEDIA ANALYSIS

4.1 Introduction

Now that the Task Analysis Report has been completed and learning categories determined, the actual decision on media can be made quickly. We have seen that the RAMP job tasks fall into six (6) of eleven (11) possible learning categories. The RAMP categories are:

1) Rule Learning and Using, Category 1
2) Classifying and Recognizing Patterns, Category 2
3) Identifying Graphic Symbols, Category 3
4) Making Decisions, Category 5
5) Recalling Bodies of Knowledge, Category 6
6) Recalling Procedures and Positioning Movement, Category 9.

The media analysis and selection methodology developed by Florida State University provides the training developer with a Decision Matrix for each of the eleven (11) possible learning categories. On each matrix, any and all media that can effectively deliver instruction for that learning category are already listed.

4.1.1 General Conclusion on CAL Viability

For all of the six learning categories listed above, the Florida State University authors of the media selection process have listed CAL as a viable alternative media.

The eleven original matrices from the U.S. Department of Defense's "Interservices Procedures for Instructional Systems Development" are attached to this Study as Appendix I.

4.1.2 Specific Conclusion on CAL Viability for RAMP Training Applications

The final step in the media selection process requires the investigator to complete the short questionnaire in each Decision Matrix with responses for a specific instructional program. Responses are based on the data contained in the TAR and on interviews with RAMP subject matter experts. A comparison is then made of the columns in which program-specific information has been entered, and the column entries for a given type of media.

4.1.2.1 CAL Viability

In the case of RAMP training, the checked responses on the Decision Matrices indicated that computer-aided learning is definitely able to provide instruction on most, if not for all of the 373 RAMP training objectives. The Media Selection Decision Matrices, filled in to reflect the learning requirements of RAMP operations and maintenance, are provided in this Section as Tables 4-1 through 4-6.

Table 4-1 Sub-Category 1 Rule Learning and Using

TYPICAL RAMP TRAINING OBJECTIVE REQUIRING RULE LEARNING AND USING ARE: INTERPRET BLOCK DIAGRAMS AND PROGRAM DIAGNOSTICS Criteria for Selecting an Instructional Delivery System in Learning Sub-Category 1	Check if Applicable to RAMP training objectives in this Learning Category	Delivery System Capabilities in this Learning Category for Computer-Aided Learning with Interactive Video and Adjunct Materials
Stimulus Criteria		
o Visual Form		
Pictorial, Plane Line Construction,	✓	X
Plane Object, Solid Environment		X
o Visual Movement		
Limited	✓	X
Full		
o Visual Spectrum		
Gray Scale	✓	X
Color	✓	X
o Audio		
Voice Sound Range		X
Full Sound Range		X
Ambient Sounds		X
o Other		
Cues		
Internal Stimulus Motion Cues		
External Stimulus Motion Cues		
Instructional Setting Criteria		
o Individual Trainee at Fixed Location	✓	X
o Individual Trainee with Independent Instruction at Any Location	✓	X
o Small Group		
o Large Group at a Single Location		
Administrative Criteria		
o Site of Courseware and Special Hardware Development		
Local		X
Central		X
o Magnitude of Acquisition Cost		
Low		X
High		X
o Can system be easily transported to remote work sites?	✓	X
o Can courseware and management data be quickly and easily collected and distributed from a central location?	✓	X

Table 4-2 Sub-Category 2 Classifying/Recognizing Patterns

TYPICAL RAMP OBJECTIVES ARE: LOCATE LRM's, IDENTIFY LRU's, CONTROLS AND INDICATORS, FAILED COMPONENTS Criteria for Selecting an Instructional Delivery System in Learning Sub-Category 2	Check if Applicable to RAMP training objectives in this Learning Category	Delivery System Capabilities in this Learning Category for Computer-Aided Learning with Interactive Video and Adjunct Materials
Stimulus Criteria		
o Visual Form		
Alphanumeric	✓	X
Pictorial, Plane Line Construction,	✓	X
Plane Object, Solid Environment		X
o Visual Movement		
Still	✓	X
Limited	✓	X
Full		
o Scale		
Exact Scale		
o Audio		
Voice Sound Range		X
Full Sound Range	✓	X
Ambient Sounds		X
o Other		
Cues		
Internal Stimulus Motion Cues		
External Stimulus Motion Cues		
Training Setting Criteria		
o Individual Trainee at Fixed Location	✓	X
o Individual Trainee with Independent Instruction at Any Location	✓	X
o Small Group		
o Large Group at a Single Location		
Administrative Criteria		
o Site of Courseware and Special Hardware Development		
Local		X
Central		X
o Magnitude of Acquisition Cost		
Low		X
High		X
o Can system be easily transported to remote work sites?	✓	X
o Can courseware and management data be quickly and easily collected and distributed from a central location?	✓	X

Table 4-3 Sub-Category 3 Identifying Graphic Symbols

TYPICAL RAMP OBJECTIVES ARE: TRACE DATA SIGNALS, TRACE COMMAND AND CONTROL SIGNALS Criteria for Selecting an Instructional Delivery System in Learning Sub-Category 3	Check if Applicable to RAMP training objectives in this Learning Category	Delivery System Capabilities in this Learning Category for Computer-Aided Learning with Interactive Video and Adjunct Materials
Training Setting Criteria		
o Individual Trainee at Fixed Location	✓	X
o Individual Trainee with Independent Instruction at Any Location	✓	X
Administrative Criteria		
o Site of Courseware and Special Hardware Development		
Local		X
Central		X
o Magnitude of Acquisition Cost		
Low	✓	X
High	✓	X
o Can system be easily transported to remote work sites?	✓	X
o Can courseware and management data be quickly and easily collected and distributed from a central location?	✓	X

Table 4-4 Sub-Category 5 Making Decisions

TYPICAL RAMP OBJECTIVES ARE: IDENTIFY REQUIREMENTS; TROUBLESHOOT AND REPAIR Criteria for Selecting an Instructional Delivery System in Learning Sub-Category 5	Check if Applicable to RAMP training objectives in this Learning Category	Delivery System Capabilities in this Learning Category for Computer-Aided Learning with Interactive Video and Adjunct Materials
Stimulus Criteria		
o Visual Form		
Alphanumeric	✓	X
Pictorial, Plane Line Construction, Plane Object, Solid Environment	✓	X
o Visual Movement		
Still	✓	X
Full Movement	✓	X
o Audio		
Voice Sound Range		X
Full Sound Range	✓	X
o Other		
Tactical Cues		
External Stimulus Motion Cues		
Training Setting Criteria		
o Individual Trainee at Fixed Location	✓	X
o Individual Trainee with Independent Instruction at Any Location	✓	X
o Small Group		X
o Team Setting		X
Administrative Criteria		
o Site of Courseware and Special Hardware Development		
Local		X
Central		X
o Magnitude of Acquisition Cost		
Low		X
High		X
o Can system be easily transported to remote work sites?	✓	X
o Can courseware and management data be quickly and easily collected and distributed from a central location?	✓	X

Table 4-5 Sub-Category 6 Recalling Bodies of Knowledge

TYPICAL RAMP OBJECTIVES ARE: DESCRIBE--MODES OF OPERATION, REPAIR PROCEDURES, POWER DISTRIBUTION, THEORY OF OPERATION, DIAGNOSTIC CAPABILITIES; STATE-REQUIREMENTS, PRECAUTIONS, PURPOSE Criteria for Selecting an Instructional Delivery System in Learning Sub-Category 5	Check if Applicable to RAMP training objectives in this Learning Category	Delivery System Capabilities in this Learning Category for Computer-Aided Learning with Interactive Video and Adjunct Materials
Stimulus Criteria		
o Visual Movement		
Limited	✓	X
Full		
o Visual Spectrum		
Full Color	✓	X
o Audio		
Voice Sound Range		X
Full Sound Rage		X
Training Setting Criteria		
o Individual Trainee at Fixed Location	✓	X
o Individual Trainee with Simultaneous Instruction at Many Location		X
o Individual Trainee with Independent Instruction at Any Location	✓	X
o Small Group		
o Large Group at a Single Location	✓	
o Team Setting		
Administrative Criteria		
o Site of Courseware and Special Hardware Development		
Local		
Central		X
o Magnitude of Acquisition Cost		
Low		X
High		X
o Can system be easily transported to remote work sites?	✓	X
o Can courseware and management data be quickly and easily collected and distributed from a central location?	✓	X

Table 4-6 Sub-Category 9 Recalling Procedures and Positioning Movement

TYPICAL RAMP TRAINING OBJECTIVES ARE: TROUBLESHOOT USING BITE AND MANUAL PROCEDURES Criteria for Selecting an Instructional Delivery System in Learning Sub-Category 1	Check if Applicable to RAMP training objectives in this Learning Category	Delivery System Capabilities in this Learning Category for Computer-Aided Learning with Interactive Video and Adjunct Materials
Complexity Criteria		
o Difficult Motor Acts		
o Smooth Motor Performance at End of Training	✓	
Stimulus Criteria		
o Visual Form		
Alpha-Numeric	✓	X
Pictorial, Plane object, Solid Object, Solid	✓	X
o Visual Movement		
Still	✓	X
Full Movement	✓	X
o Audio		
Voice Sound Range		X
Full Sound Range	✓	X
Ambient Sounds		X
o Other		
Tactile Cues		
Internal Stimulus Motion Cues		
Training Setting Criteria		
o Individual Trainee at Fixed Location	✓	X
o Individual Trainee with Independent Instruction at Any Location	✓	X
o Small Group		
o Large Group at a Single Location		
o Team Setting		X
Administrative Criteria		
o Site of Courseware and Special Hardware Development		
Local		
Central		X
o Magnitude of Acquisition Cost		
Low		X
High		X
o Can system be easily transported to remote work sites?	✓	X
o Can courseware and management data be quickly and easily collected and distributed from a central location?	✓	X

4.1.2.2 Some Observer/Supervisor Attention Still Required

In interviews with Raytheon RAMP subject matter experts, the point was made that in on-job sustainment or proficiency and refesher training, some RAMP operations and maintenance tasks, in particular, require that strict attention be paid to safety requirements. Of perhaps equal importance is the extreme criticality of some tasks. It was the opinion of RAMP subject matter experts that the training objectives with special safety and/or task criticality considerations would be a particular concern to FESD. Further, it was suggested that FESD might want to have job proficiency on these special tasks regularly demonstrated in a hands-on environment under co-worker, if not supervisory observation. Clearly, this real, supervised performance is beyond the capability of CAL to simulate with 100% fidelity. On the other hand, it was agreed that CAL could deliver training on the cognitive and problem-solving aspects of these tasks.

Therefore, it is the conclusion of this study that CAL can train portions of all required RAMP tasks, and most tasks completely.

4.2 Additions to the Media Selection Decision Matrices

Due to the fact that the media appearing on the decision matrices date from 1975, as well as the existence of special FESD requirements for training, the Media Selection Decision Matrices have been updated with new CAL descriptions and additions of questions on hardware portability and centralized control of courseware.

4.2.1 CAL with Interactive Video and Adjunct Material

Since 1975, incredible advances in computer technology have occurred. These improvements have caused us to redefine Computer Assisted Instruction (CAI) as it appeared on the original matrices. For the purposes of this Study, we are defining CAL/CAI delivery media both as the expensive mainframe computer of the 70's and the microcomputer-based system of today. Moreover, the power of the present microcomputer has been greatly enhanced by the addition of videotape and videodisc systems played under the precise and programmable control of the micro. Instructional programs running on these systems also frequently employ off-line text material and/or technical manuals. Therefore, we have upgraded the definition of "CAL" to read "CAL with interactive video and adjunct material".

The reader will also note that the response to the question on the cost of the media has been changed from a check next to "High" cost to two checks, one next to "High", and one next to "Low", since both price ranges now exist.

4.2.2 Requirements for System Portability

The discussion of CAL in "Maintenance 2000" clearly indicated a belief that CAL should be considered for proficiency and refresher training delivered at the worksite, rather than incurring the expense of returning the technician to TCTI for a course. This clearly implies the need for a portable CAL system. Therefore, this question has been added to the media criteria for CAL. A "yes" check has been placed next to this question reflecting the CAL system portability achieved by such hardware system producers as IBM, Sony, and Matrox.

4.2.3 Requirements for Centralized Collection and Dissemination of Course and Management Data

A CAL system requirement that springs from portable, remotely-sited CAL systems is the need to control the software in use on these units, their updates as well as adjunct materials, and the requirement to gather performance and proficiency data on each employee. A question has, therefore, been added to the list of CAL media criteria which asks whether the system allows for ease of data collection and dissemination. A "yes" has been added to CAL column, reflecting the capability of computers to be interconnected via modem or other data links. Additionally, the small size of software diskettes and videotape and disc products lend themselves to distribution via the postal system or similar means of surface dispatch.

4.2.4 Approach to System Cost Questions

Cost judgements on Cal for RAMP training are presently very premature and outside the scope of this study. Therefore, no program-specific cost estimations have been attempted.

The authors believe that the cost and productivity analysis required to determine the economic and personnel benefits of CAL should be the subject of a separate undertaking.

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August 31, 1988

Aerodevco Consultants Ltd.
130 Slater Street,
Suite 1026
Ottawa, Ontario
K1P 6E2

Balance due Sypher:Mueller International Inc. from Dunvegan Computer Systems	$ 1,374.91
Interest on outstanding balance	$ 27.49
TOTAL DUE:	$ 1,402.40

APPENDIX A

Original 1975 Florida State University
Media Selection Decision Matrices

Sub-Category 1: Rule Learning and Using

Directions:

To choose a delivery system:

1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (columns) that have an "X" in each row designated by a "√". These are the candidate delivery systems.

Criteria for Selecting Instructional Delivery Systems		Alternative Instructional Delivery Systems									
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm							Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm		
		Operational Equipment with Instructor and Instructor Handbook	Simulator with Instructor and Instructor Handbook	Procedure Trainer with Instructor and Instructor Handbook	Computer Assisted Instruction	Teaching Machine, Branching	Programmed Text, Branching	Microfiche with Self-Scoring Tests	Traditional Classroom	Programmed Instruction - Linear	
Stimulus Criteria											
● Visual Form											
Pictorial, Plane					X	X	X	X	X	X	
Line Construction, Plane					X	X	X	X	X	X	
Object, Solid		X	X	X					X		
Environment		X	X	X							
● Visual Movement											
Limited			X	X	X	X			X		
Full		X	X	X	X						
● Visual Spectrum											
Gray Scale					X	X	X	X	X	X	
Color		X	X	X	X	X		X	X		
● Audio											
Voice Sound Range		X	X	X	X	X			X		
Full Sound Range		X	X	X							
Ambient Sounds		X	X								
● Other											
[illegible] Cues		X	X	X							
Internal Stimulus Motion Cues		X	X	X							
External Stimulus Motion Cues		X	X								
Instructional Setting Criteria											
● Individual Trainee at Fixed Location		X	X	X	X	X	X	X	X	X	
● Individual Trainee with Independent Instruction at Any Location							X	X		X	
● Small Group									X		
● Large Group at a Single Location									X		
Administrative Criteria											
● Site of Courseware and Special Hardware Development											
Local							X	X	X	X	
Central		X	X	X	X	X	X	X		X	
● Magnitude of Acquisition Cost											
Low				X		X	X	X	X	X	
High		X	X	X	X	X					

Sub-Category 2: Classifying

Directions:

To choose a delivery system:

1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (columns) that have an "X" in each row designated by a "√". These are the candidate delivery systems.

Criteria for Selecting Instructional Delivery Systems		Alternative Instructional Delivery Systems										
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm					Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm					
		CAI w/Adjunct Equipment and Materials	Study Card Sets	Microfiche	Teaching Machine - Branching	Simulator with Adjunct Displays or Instructor	Slide Sets with Instructor	Traditional Classroom with AV Materials	Audio Recorders - Disc or Tape	Specimen Set	Sound Slide/Film Strip Program	
Stimulus Criteria												
● Visual Form												
Alphanumeric		X	X	X	X	X	X	X			X	
Pictorial, Plane		X	X	X	X		X	X			X	
Line Construction, Plane		X	X	X	X		X	X			X	
Object, Solid						X				X		
Environment						X						
● Visual Movement												
Still		X	X	X	X		X	X		X	X	
Limited		X			X			X			X	
Full						X		X				
● Scale												
Exact Scale						X				X		
● Audio												
Voice Sound Range		X			X	X	X	X	X		X	
Full Sound Range						X			X			
Ambient Sounds						X						
Other Tactile Cues						X				X		
Internal Stimulus Motion Cues						X						
External Stimulus Motion Cues						X						
Training Setting Criteria												
● Individual Trainee at a Fixed Location		X	X	X	X	X	X		X	X	X	
● Individual Trainee with Independent Instruction at Any Location			X	X					X		X	
● Small Group							X	X	X		X	
● Large Group at Single Location							X	X	X		X	
Administrative Criteria												
● Site of Courseware and Special Hardware Development												
Local			X	X	X		X	X	X	X	X	
Ce:		X	X	X	X	X	X	X	X	X	X	
● Magnitude of Acquisition Cost												
Low			X	X			X	X	X	X	X	
High		X			X	X						

Sub-Category 3: Identifying Graphic Symbols

Directions:

To choose a delivery system:

1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (columns) that have an "X" in each row designated by a "√". These are the candidate delivery systems.

Criteria for Selecting Instructional Delivery Systems		Alternative Instructional Delivery Systems									
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm					Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm				
		CAI (with visual display)	Teaching Machine - Branching	Programmed Text - Branching	Microfiche with Self-Scoring Tests	Study-Card Sets with Self-Scoring Tests	Traditional Classroom	Textbook	Chart	Automatic Rater	
Training Setting Criteria											
● Individual Trainee at a Fixed Location		X	X	X	X	X		X	X	X	
● Individual Trainee with Independent Instruction at Any Location				X	X	X		X	X		
Administrative Criteria ● Site of Courseware and Special Hardware Development											
Local				X	X	X	X	X	X	X	
Central		X	X	X	X	X		X	X	X	
● Magnitude of Acquisition Cost											
Low				X	X	X	X	X	X	X	
High		X	X								

Sub-Category 4: Detecting

Directions:

To choose a delivery system:

1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (columns) that have an "X" in each row designated by a "√". These are the candidate delivery systems.

Criteria for Selecting Instructional Delivery Systems		Alternative Instructional Delivery Systems							
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm					Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm		
		Operational System with Stimulated Signals, and an Instructor with Instructor Handbook	Simulator with Instructor and Instructor Handbook	Simulator with Adjunct Displays and Logic	Procedure Trainer, with Instructor and Instructor Handbook	Procedure Trainer with Adjunct Displays and Logic	Operational System with Instructor	Informal On-the-Job Training on Operational System	
Stimulus Criteria									
● Full Visual Environment		X					X	X	
● Full Ambient Sounds		X	X	X			X	X	
● External Stimulus Motion Cues		X	X	X			X	X	
Training Setting Criteria									
● Individual Trainee at Fixed Location (School)		X	X	X	X	X	X		
● Individual Trainee On-the-Job		X					X	X	
Administrative Criteria									
● Site of Courseware and Special Hardware Development									
Local							X	X	
Central		X	X	X	X	X			
● Magnitude of Acquisition Cost									
Low								X	
High		X	X	X	X	X	X		

Sub-Category 5: Making Decisions

Directions:

To choose a delivery system:

1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (columns) that have an "X" in each row designated by a "√". These are the candidate delivery systems.

Criteria for Selecting Instructional Delivery Systems		Alternative Instructional Delivery Systems									
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm						Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm			
		Simulator Diagnostic Tests with Instructor	Manual Simulation Game with Diagnostic Tests and Instructor	CAI with Adjunct Equipment and Materials	Teaching machine - Branching	Microfiche with Self-Scoring Tests	Programmed Text - Branching with Self-, Scoring Tests	Operational System with Tutor	Case Study Materials w/wo Instructor	Role Playing Materials with Instructor	
Stimulus Criteria											
● Visual Form											
Alphanumerics			X	X	X	X	X		X	X	
Pictorial, Plain			X	X	X	X	X		X	X	
Object, Solid		X						X		X	
● Visual Movement											
Still			X	X	X	X	X		X		
Full Movement		X		X				X			
● Audio											
Voice Sound Range		X	X	X	X			X		X	
Full Sound Range		X						X			
● Other											
Tactile Cues		X						X			
External Stimuli Motion Cues		X						X			
Training Setting Criteria											
● Individual Trainee at Fixed Location		X	X	X	X	X	X	X	X		
● Independent Trainee with Independent Instruction at Any Location						X	X				
● Small Group								X	X	X	
● Team Setting		X	X					X		X	
Administrative Criteria											
● Site of Courseware and Special Hardware Development											
Local			X			X	X		X	X	
Central		X	X	X	X	X	X	X	X	X	
● Magnitude of Acquisition Cost											
Low			X			X	X		X	X	
High		X		X	X			X			

Sub-Category 6: Recalling Bodies of Knowledge

Directions:

To choose a delivery system:

1. Place a "✓" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (columns) that have an "X" in each row designated by a "✓". These are the candidate delivery systems.

Criteria for Selecting Instructional Delivery Systems		Alternative Instructional Delivery Systems								
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm					Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm			
		CAI	Teaching Machine - Branching	Microfiche with Self-Scoring Tests	Programmed Text - Branching with Self-Scoring Tests	Audio Visual Carrel with Program Texts, AV Modules and Self-Scoring Tests	Traditional Classroom with Instructor, Overhead Projector, Texts, and Paper and Pencil Tests	Independent Study Using Textbooks, Handbooks, Tests and Workbooks	Instructional Television Broadcast or CCTV without Feedback, Tests	Programmed Text - Linear with Instructor Scored Criterion Test
Stimulus Criteria										
● Visual Movement										
Limited		X	X			X			X	
Full		X				X			X	
● Visual Spectrum										
Full Color		X	X	X		X	X	X	X	
● Audio										
Voice Sound Range		X	X			X	X		X	
Full Sound Range						X				
Training Setting Criteria										
● Individual Trainees at Fixed Location		X	X	X	X	X	X		X	X
● Individual Trainees with Simultaneous Instruction at Many Locations									X	
● Individual Trainees with Independent Instruction at Any Location				X	X			X		X
● Small Group							X		X	
● Large Group at a Single Location							X		X	
● Team Setting										
Administrative Criteria										
● Site of Courseware and Special Hardware Development										
Local				X	X	X	X	X		X
Central		X	X	X	X	X		X	X	X
● Magnitude of Acquisition Cost										
Low				X	X		X	X		X
High		X	X			X			X	

Sub-Category 7: Performing Gross Motor Skills

Criteria for Selecting Instructional Delivery Systems	Directions: To choose a delivery system: 1. Place a "/" (light pencil) in boxes representing criteria (rows) that must be met. 2. Select the delivery systems (columns) that have an "X" in each row designated by a "/". These are the candidate delivery systems.	Alternative Instructional Delivery Systems				
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm		Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm		
		Tutor in a Job-Like Setting with Equipment, if required, an Instructor Handbook and Student Diagnostic Tests	Tutor in a Job-Like Setting with equipment, if required, an Instructor Handbook, Student Diagnostic Tests, and Portable TV with a Record/Playback Capability and a Series of Taped Demonstrations	Programmed Text - Branching and a Series of Film Loops with Equipment, if required, and a Part-Time Instructor with Criterion Tests	Supervisor Managed Informal On-The-Job Training	
Training Setting Criteria						
● Individual Trainee at a Fixed Location		X	X	X		
● Individual Trainee with Independent Instruction at Many Locations				X	X	
● Small Group					X	
● Team Setting		X	X		X	
Administrative Criteria						
● Site of Courseware Development						
Local		X	X	X	X	
Central		X	X	X		

Sub-Category 8: Steering and Guiding - Continuous Movement

Directions:

To choose a delivery system:

1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (columns) that have an "X" in each row designated by a "√". These are the candidate delivery systems.

Criteria for Selecting Instructional Delivery Systems		Alternative Instructional Delivery Systems					
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm				Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm	
		Operational System, Real Environment with Instructor and Instructor Handbook	Simulator with Motion Platform and Full Visual Field, Instructor and Instructor Handbook	Simulator (Without Motion Platform and Full Visual Field) Instructor and Instructor Handbook	Procedure Trainer, Instructor and Instructor Handbook	Operational System, Real Environment, Without Instructor	
Stimulus Criteria							
Full Visual Environment		X	X			X	
External Stimulus Motion Cues		X	X			X	
Fine Movement Manipulative Acts		X	X	X		X	
Broad Movement Manipulative Acts		X	X	X	X	X	
Training Setting Criteria							
Individual or Team Training at a Fixed Location		X	X	X	X	X	
Individual or Team Training with Independent Instruction at Many Locations		X				X	
Administrative Criteria							
Site of Courseware and Special Hardware Development							
Local		X				X	
Central		X	X	X	X	X	

Sub-Category 9: Recalling Procedures and Positioning Movement

Directions:

To choose a delivery system:

1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (columns) that have an "X" in each row designated by a "√". These are the candidate delivery systems.

Criteria for Selecting Instructional Delivery Systems		Alternative Instructional Delivery Systems											
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm								Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm			
		Operational System in Laboratory with Tutor	Simulator with Tutor and Tests	Procedures Trainer with Tutor and Tests	Logic Trainer with Tutor	CAI with Photo or Operable Mockup	Teaching Machine with Photo or Operable Mockup	Microfiche w/wo Photo or Operable Mockup	Programmed Text - Branching	Laboratory Carrel with, Equipment and Linear Instructional Materials	Operational System in Real Environment with Tutor	Texts, Lectures and Demonstrations	
Complexity Criteria													
● Difficult Motor Acts		X	X	X	X					X	X		
● Smooth Motor Performance at End of Training		X	X	X						X	X		
Stimulus Criteria													
● Visual Form													
Alpha-Numeric		X	X	X	X	X	X	X	X	X		X	
Pictorial, Plane					X	X	X	X	X	X		X	
Object, Solid		X	X	X	X					X	X	X	
● Visual Movement													
Still					X	X	X	X	X	X		X	
Full Movement		X	X	X	X	X				X	X		
● Audio													
Voice Sound Range		X	X	X		X				X	X	X	
Full Sound Range		X	X	X						X	X		
Ambient Sounds		X	X	X							X		
● Other													
Tactile Cues		X	X	X						X	X		
Internal Stimulus Motion Cues		X	X	X						X	X		
Training Setting Criteria													
● Individual Trainee at Fixed Location		X	X	X	X	X	X	X	X	X	X	X	
● Individual Trainee with Independent Instruction at Any Location								X	X				
● Small Group					X							X	
● Large Group at Single Location												X	
● Team Setting		X	X	X	X						X		
Administrative Criteria													
● Site of Courseware and Special Hardware Development													
Local								X	X	X	X	X	
Central		X	X	X	X	X	X	X	X	X	X		
● Magnitude of Acquisition Cost													
Low								X	X	X		X	
High		X	X	X	X	X	X			X	X		

Sub-Category 10: Voice Communicating

Directions:

To choose a delivery system:

1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (columns) that have an "X" in each row designated by a "√". These are the candidate delivery systems.

Criteria for Selecting Instructional Delivery Systems		Alternative Instructional Delivery Systems							
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithms			Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithms				
		Simulator with Instructor, Instructor Handbook, and Diagnostic Tests	Procedure Trainer with Instructor, Instructor Handbook and Diagnostic Tests	Language Laboratory, Audio, Active-Compare Mode, with Manual Simulation Game and Instructor	Language Laboratory, Audio, Active-Compare Mode, with Printed Materials	Performance Aid	Traditional Classroom	Operational Equipment in Real Environment with Instructor	
Stimulus Criteria									
● Visual Form									
Pictorial, Plane				X	X	X	X		
Solid Object		X	X					X	
● Visual Movement									
Still				X	X	X	X		
Full Movement		X	X					X	
● Audio									
Voice Sound Range		X	X	X	X		X	X	
Ambient Sounds		X	X	X	X			X	
Training Setting Criteria									
● Individual Trainee at a Fixed Location		X	X	X	X		X	X	
● Individual Trainee with Independent Instruction at Any Location						X			
● Team Setting		X	X	X		X		X	
Administrative Criteria									
● Site of Courseware and Special Hardware Development									
Local						X	X	X	
Central		X	X	X	X	X			
● Magnitude of Acquisition Cost									
Low				X	X	X	X		
High		X	X					X	

Sub-Category 11

This chart is useful in selecting an instructional delivery system for the affective and behavioral components of attitude learning. For achieving the cognition component use instructional delivery systems suggested for recalling bodies of knowledge

ATTITUDE LEARNING

Directions:

To choose a delivery system:

1. Place a "√" (light pencil) in boxes representing criteria (rows) that must be met.

2. Select the delivery systems (column) that have an "X" in each row designated by a "√". These are the candidate delivery systems.

Criteria for Selecting Instructive Delivery Systems		Alternative Instructional Delivery Systems						
		Delivery Approaches Permitting the Application of All Learning Guidelines and Algorithm		Delivery Approaches NOT Permitting Complete Application of Learning Guidelines and Algorithm				
		Operational Job Setting with Instructor and Instructor Handbook with Diagnostic Attitude Tests	Simulated Job Setting with Instructor and Instructor Handbook with Diagnostic Attitude Tests	Roll Playing	Case Studies	On-The-Job Training by Supervisors	Lectures, Seminars, etc.	
Training Setting Criteria								
● Individual Trainee at Fixed Location		X	X		X			
● Individual Trainee with Independent Instruction at Many Locations						X	X	
● Small Group		X	X	X	X	X	X	
● Team Setting		X	X	X	X	X	X	
Administrative Criteria ● Site of Courseware Development								
Local		X		X	X	X	X	
Central		X	X	X	X			
● Magnitude of Acquisition Cost								
Low				X	X	X	X	
High		X	X					

STEP III

REPORT AND RECOMMENDATIONS REGARDING ERGONOMICALLY SUITABLE I/O DEVICES FOR TRAINING WORKSTATION

5. ERGONOMICALLY SUITABLE I/O DEVICES

5.1 Introduction

Although the matter of media selection in terms of appropriate I/O devices was addressed to some degree in the previous section, no attempt was made there to specify hardware for the training station. The task of Step III, therefore, is to provide a list of I/O devices capable of delivering the range of training materials required to support the maintenance of RAMP. Each of the recommended I/O devices in themselves meet generally accepted ergonomic standards, but the ultimate suitability of these devices on ergonomic terms must be evaluated in the context of the training workstation as a whole.

It will be noted that the selection of I/O devices assumes a requirement of system portability, hence the specification of mircoprocessors. The recommendations of MS-DOS compatible equipment is based on an awareness of the proliferation of such equipment within Transport Canada and upon recognition for software flexibility as well as ease of compatibility with interactive videodisc machines.

5.2 Recommended I/O Devices

The training workstation needs to contain the following I/O devices in order to satisfy the RAMP maintenance training requirements:

- MS-DOS compatible microcomputer with 8 expansion slots, 10 megabyte hard-disk, minimum 512 R RAM, 2 floppy drives, 6-8 Mhz.
- Expansion board with clock calendar, 2 serial ports and 1 parallel port.
- Colour graphics adapter and cables.
- Colour graphics display monitor capable of handling both RGB and composite signals, and having volume, colour, contrast and brightness controls.
- Graphics overlay board.
- Mouse or touchscreen as alternate output devices utilizing one serial port.
- Keyboard.
- 1200 BPS internal modem.
- Videodisc/videotape hardware, cabling and interface to CPU.
- Video cables to facilitate software switching between RGB and composite.

- Printer - 80 columns, DOT matrix, capable of reproducing bit images.

5.3 Physical and Environmental Context

The study assumes that the training stations will be situated in a typical office-like environment in virtually all locations with some variance occurring in terms of lighting, privacy and temperature. The scope of the study does not permit the quantifying of these variances in each and every location. In practice, this means that most sites will not be specially adopted or adaptable to workstation utilization in such areas as lighting, ventilation, heating, sound isolation and so on. The design of the workstation should be appropriate for use in as broad a range of environmental conditions as may be found in office environments constructed within the last 40 years and where extensive renovations have not been undertaken.

5.4 User Profile for a Work Station for the Training of Electronics Technicians

It is anticipated that there will be a user population for the training workstation of some 1200 technicians across Canada. Of these some 95%+ will be male. Their average age will be 30. They will have a degree of computer literacy (from their training programs), although the younger trainees will be more experienced with computers than the older ones. They will generally however, only have limited keyboard skills (hunt and peck).

It is not the case that the workstation will have to be designed so as to accommodate those with severe physical handicaps since a criteria of selection for the post is "good physical condition". An average height and weight range for males (5'2" to 6'2" and 150-250 lbs.) is to be allowed for in the system design. The system will however, have to accommodate those confined to wheelchairs. Those with palsy or colour blindness will be excluded from the position as will those who are totally deaf, but those with limited eye or hearing defects will be using the system.

The system will be used about 1/6 of time by Francophones and thus should be fully bi-lingual in design. In addition the system should be equipped to accommodate left-handed users.

STEP IV

REPORT ON SOFTWARE REQUIREMENTS,
INCLUDING SUITABILITY OF RECOMMENDED
I/O DEVICES GIVEN THE USE OF THE NATAL AUTHORING LANGUAGE

6. SOFTWARE REQUIREMENTS

6.1 Introduction

The RAMP Task Analysis Study established that maintenance training activities of the system fell into six (6) of eleven (11) possible learning categories. The Media Analysis determined that computer-assisted learning is able to satisfy most, if not all, of the 373 RAMP training objectives. The I/O devices selected in Step III of this Ergonomics Characteristics Study give to the training station hardware interactive capability to present to the trainee (within the limits of ergonomic criteria) the full range of learning materials required to satisfy RAMP's maintenance training objectives in the identified learning categories.

The assessment of software requirement, undertaken as Step IV of this Ergonomics Characteristic Study addressed the following criteria:

1) functionality to optimize the interactive capability of the recommended I/O devices in the training station and to satisfy ergonomic factors of interactive computer systems described in the Literature Review, Sections 1.4, 1.5, and 2.2;

2) suitability for use given the existing level of knowledge and skill of trainees;

3) suitability for use given the content of the requisite maintenance training program identified for the RAMP system;

4) suitability for use given the environmental conditions to be found in most anticipated sites;

5) ease of use by the trainee;

6) error rates;

7) applicability for bilingual use;

8) suitability of NATAL as an authoring language; and

9) availability of alternative authoring and presentation systems.

What the Software Requirements Assessment does not address are the instructional design ergonomic issues which would emanate from the courseware authoring process itself. For example, it is not within the scope of this study to examine the most effective ways of presenting specific lesson content. The recommendations therefore are general to meeting the software requirements of the selected I/O devices and the high level functional criteria listed above.

6.2 Interactive Software Capability

To optimize the interactive capability of the recommended I/O devices in the training station and to satisfy the ergonomic factors of interactive computer-based training systems described in the Literature Review, Sections 1.4, 1.5 and 2.2, the software requirements are listed in five (5) contexts: minimum functionality to operate the training station, authoring facilities, management capabilities, documentation/training, and communications. The methodology used in preparing these lists involved the modifying of an "Authoring System Selection Checklist" developed by Oakridge University, Tennessee on behalf of the United States Army to include specific functional criteria referenced in the Literature Review and highlighted by the RAMP Media Study.

6.2.1 Minimum Functionality

Assuming I/O devices configuration based upon IBM PC or compatible microprocessor, videodisk player and the use of the combination of interactive styles employing the key-board and the mouse, the minimum software requirements of the training station are as follows:

1) ram disk software (included in DOS 3.00) to heighten system performance by reducing disk access;

2) ability to present text, graphic and video material and to superimpose text over text, text over graphics, text over video, graphics over video, and text and graphics over video;

3) interactive videodisc software interfaces and controls enabling both video and audio integration into courseware;

4) security through trainee passwords and authorization levels determined by training manager;

5) further software security provided through special software security protocol;

6) restart capabilities;

7) scrolling and windowing;

8) animation of graphics to enhance teaching points; and

9) easy to distinguish special symbols (ICONS) in menu and frame displays which have a high level of association with the objects they represent.

6.2.2 Authoring Facilities

In order to optimize training effectiveness in the self-paced learning environment provided by the computer-based training station, stimulating courseware accessed through upper friendly man-machine interfaces must be provided to the trainees. Authoring facilities for the development of courseware to deliver maintenance training on the RAMP system should contain most of the following features:

6.2.2.1 Text

1) Variable text colours;
2) Multiple character points;
3) Ability to create special points and character sets;
4) Ability to underline, italicize, shadow outline and make bold;
5) Proportional spacing;
6) Directional typing; and
7) Full word processing capbilities, including
    - word wrap
    - margin setting
    - inserting and deleting of characters, words and lines
    - search and replace ability
    - ability to move blocks of text
    - spelling checker.

6.2.2.2 Sequencing

1) Linear;
2) Branching;
3) Multiple branching; and
4) Branching based on student response.

6.2.2.3 Testing

1) Questions:
    - Multiple choice
    - Fill-in-the-blank
    - Keyword search/free form response
    - List match
    - List select
    - Yes/No
    - True/False
    - Return to continue.

2) Responses:
    - Multiple characters per response
    - Multiple responses per screen
    - Learner able to redo response
    - Close answers accepted
    - Multiple correct answers

6.2.2.4 Graphics

1) Internal graphics
2) Superimpose text over graphics
3) Superimpose text over videodisc
4) Superimpose graphics over videodisc
5) Superimpose text and graphics over videodisc
6) Windowing
7) Free-form graphics capability
8) Availability of an existing graphics library
9) Availability to add to and/or edit images in the graphics library
10) High resolution graphics
11) Colour graphics
12) Multiple graphics on screen
13) Multiple input devices for graphics creation
    - keyboard
    - light pen
    - mouse
    - graphics tablet

6.2.2.5 Audio

1) Still-frame audio
2) Supports computer-generated sounds

6.2.2.6 Interface Methods

1) Interface with videodisc
2) Interface with other software packages
3) Interface with programming language
4) Supports light pen
5) Supports touch sensitive screen
6) Supports mouse
7) Supports graphics tablet

6.2.2.7 Editing Methods

1) Text
    - menu driven editing
    - ability to title each screen
    - ability to number each screen
    - dictionary function
    - branch checking
    - ability to resequence lesson screens
    - preview of lesson delivery from authoring system

2) Graphics
   - menu driven editing
   - paint function (paintbrush, spraypaint)
   - rotate
   - scale
   - mirror
   - copy
   - screen capture from other locations
   - zoom
   - shrink and enlarge images
   - overlay - (transparent, opaque, merge, negative image)

3) Videodisc
   - play video from system
   - rewind video from system
   - fast forward video from system
   - pause video from system
   - ability to assign title/numbers to video segments
   - ability to connect all text, audio/video and graphics segments
   - ability to designate video frame beginning and end points

4) Prompting
   - menu-driven
   - menu-by-pass

6.2.3 Management Capabilities

6.2.3.1 Types of records

1) Individual records
2) Group records
3) Individual responses
4) On-line student registration

6.2.3.2 Methods Used

1) Management contained in authoring system

6.2.4 Documentation/Training

6.2.4.1 Manuals

1) Reference manual
2) Tutorial
3) Embedded in system

6.2.4.2 Train-the-Trainer Support

1) On-site
2) Vendor facility

6.2.5 Communications

It is recommended that the stand-alone, training work station for maintenance refresher training support telecommunications links which permit centralized collection of administrative and test response data. The ability of a trainee in one location to communicate through this link with the instructor would be a desireable feature. The ability of a trainee to communicate through this link with a trainee in another location is not required. On the one hand, such communications could be an effective trainee motivator. On the other hand it would be susceptible to misuse leading to distraction and frivolous use of the training station. A further consideration, of course, is the cost of supporting a national electronic mail capability.

6.3 Suitability for Use By Existing Trainee Population

Given that the selected I/O devices in the training station withstand the ergonomic standards appropriate to the socio-demographic and physiometric range of anticipated trainees, as described in section 5.2 (Report and Recommendations Regarding Ergonomically Suitable I/O Devices for Training Station), there are a number of software considerations prompted by these same trainee population factors. Key considerations addressable through software include the capabilities noted below.

6.3.1 Ease of Use

The trainee must be provided with a combination of styles of interaction that serve to dimish impediments in learning caused by negative feelings about receiving training via a machine that range from anxiety to downright stubborness. In the case of the maintenance technicians, however, it is reasonable to assume that the large majority of them are comfortable with machines and will adapt relatively quickly and painlessly to using the computer and videodisc I/O devices in the training station. To abett the familiarization process and aid the learning efficiency of the trainees, the following software driven man-machine interfaces are recommended.

6.3.1.1 Minimum Reliance on the Keyboard

It is assumed that the trainees for the most part will not possess touch typing skills, hence a menu-driven system enabling direct manipulation through either the use of a mouse or touch-screen would be the most acceptable styles of interaction. In regard to the ergonomic merits of the mouse versus touchscreen, it is our view that the mouse is less tiring and distracting to the material on the screen. The mouse also better utilizes both hardware and software capacity and flexibility in the mirco environment. Use of the keyboard should be restricted to RETURN and ESCAPE keys, space bar and a small number of easy to remember alpha-numeric function keys.

6.3.1.2 Software Transparency

The trainee population should be oblivious to the software and concerned only with the content of the courseware, and ease of access.

6.3.1.3 Error Rates

A major deterrent to effective CAL is courseware author initiated logic and syntax errors. Authoring languages such as NATAL are more prone to such errors due to the need to programme the courseware. CBT authoring systems based upon a "what you see is what you get" approach, on the other hand, make it much easier and less time consuming to produce error-free lessons. Using CBT authoring systems, once screens are created and the responses and branching has been specified, the assembly of the course will indicate errors and editing is accomplished immediately on the screen without having to go back into a code.

6.3.1.4 Legibility/Visibility

Software is used to determine colour selection, the size of fonts, juxtaposition of foreground and background colours and shapes, quantity and organization of material on the screen. Notwithstanding the fact that these and many others instructional design considerations are explored in considerable detail within the body of the Literature Review, a full evaluation of legibility/visibility factors would take into account actual lesson content characteristics of items such as colour-coded wiring diagrams, detailed circuiting schematics, etc. However, we can attest that the authoring facilites described in 6.2 have the capacity to solve most legibility/visibility objectives provided the selected hardware permits.

6.3.2 Applicability for Bilingual Use

It is a requirement of the authoring system that course materials can be developed in English and French. Both NATAL authoring language and the CBT authoring software have this capability.

6.4 Suitability of NATAL as an Authoring Language

The study compared the functionality of the micro version of the NATAL authoring language against an Authoring System Selection Checklist developed by Oakridge University, Tennessee and modified to include function criteria referenced in the Literature Review and highlighted by the RAMP Media Study. The checklist, which also compares the functionality of a selected course authoring software system, follows as Table 6-1. It is the conclusion of this examination that the micro version of NATAL has sufficient capability to produce courseware requisite to RAMP maintenance training requirement.

6.5 Alternative Authoring and Presentation Systems

With regard to the proceeding courseware authoring and presentation system evaluation, it is important to note that the selected CBT system appears to require fewer resources and less time to create equivalent quality courseware. CBT requires the abilities of an instructional designer and subject matter expert(s), whereas NATAL not only has the same requirements, but also an additional need for programmers to code the courseware. Another consideration in selecting the course authoring system involves graphic capability. Screen creation is made very easy in the CBT software used in the above evaluation through the provision of a powerful graphics sub-system, whereas NATAL is restricted to the use of graphics primatives.

Table 6-1 Authoring System Selection Checklist

	NATAL	CBT
HARDWARE		
Microcomputer Brands/Models		
- For micro-based systems only	X	X
- Compatible with IBM PC	X	X
Brand/Model Peripheral Equipment		
- Videodisc interface	X	X
- Videotape interface	X	X
- Vdisc/Vtape interface controller required	X	X
Configuration Required for Authoring, Presenting, Managing		
- Two disk drives required	X	X
- Uploading to mini or mainframe	X	-
Display Capabilities		
- Colour graphics	X	X
- 40 column characters	X	X
- 80 column characters	X	X
- Upper case characters	X	X
- Lower case characters	X	X
OUTPUT		
Type of Instruction Development		
- Tutorial	X	X
- Test	X	X
AUTHORING FACILITIES		
Text		
- Variable text colour	X	X
- Multiple character fonts	X	X
- Able to create special fonts and character sets	X	X
- Variable characters sets	X	X
- Overlay text on text	X	X
- Supports ACSII characters	X	X
- High resolution text	X	X
- Underline	X	X
- Italicize	X	X
- Shadow	X	X
- Outline	X	X
- Bold words	X	X

Table 6-1 Authoring System Selection Checklist (cont'd)

	NATAL	CBT
Text (cont'd)		
- Proportional spacing	X	X
- Directional typing	X	X
- Word processing		
. word wrap	X	X
. margin setting	X	X
. inserting and deleting of characters, words and lines	X	X
. search and replace	X	X
. move blocks of text	X	X
. spelling checker	-	-
Sequencing		
- Linear	X	X
- Branching	X	X
- Multiple branching	X	X
- Branching based on student response	X	X
Testing		
Questions:		
- Multiple choice	X	X
- Fill-in-the-blank	X	X
- Keyword search/free form response	X	X
- List match	X	X
- List select	X	X
- Yes/No	X	X
- True/False	X	X
- Return to continue	X	X
Responses:		
- Multiple characters per response	X	X
- Multiple responses per screen	X	X
- Learner able to redo response	X	X
- Close answers accepted	X	X
- Multiple correct answers	X	X
Graphics		
- Internal graphics	X	X
- Superimpose text over graphics	X	X
- Superimpose text over Vdisc/Vtape	X	X
- Superimpose graphics over Vdisc/Vtape	X	X
- Windowing	X	X
- Free-Form graphics capability	-	X
- Existing graphics library	-	X

Table 6-1 Authoring System Selection Checklist (cont'd)

	NATAL	CBT
Graphics (cont'd)		
- Ability to add to and/or edit images in graphics library	-	X
- High resolution graphics	X	X
- Multiple graphic items on screen	X	X
Graphics Creation:		
- Via keyboard	X	X
- Via light pen	X	X
- Via mouse	X	X
- Via graphics tablet	X	X
Audio		
- Still-frame audio	X	X
- Supports computer-generated sounds	X	X
Interface Methods		
- Interface W/Videotape	X	X
- Interface W/Videodisc	X	X
- Interface W/Other software packages	X	X
- Interface W/Programming language	X	-
- Supports light pen	X	-
- Supports touch sensitive screen	X	-
- Supports mouse	X	X
- Supports graphics tablet	X	-
Editing Methods		
Text:		
- Menu Driven editing	X	X
- Ability to title each screen	X	X
- Ability to number each screen	X	X
- Dictionary function	-	X
- Branch checking	X	X
- Ability to resequence lesson screens	X	X
- Preview of lesson delivery from authoring system	X	X
Graphics:		
- Menu driven editing	-	X
- Paint function-paintbrush	X	X
- -spraypaint	-	X
- Rotate graphics	-	X
- Scale graphics	X	X

Table 6-1 Authoring System Selection Checklist (cont'd)

	NATAL	CBT
Graphics (cont'd)		
- Mirror graphics	-	X
- Move graphics	-	X
- Copy graphics	-	X
- Screen capture from other applications	-	X
- Zoom graphics	-	X
- Shrink and enlarge images	-	X
- Overlay . transparent	-	X
. opaque	-	X
. merge	-	X
. negative image	-	X
Video:		
- Play video from system	X	X
- Rewind video from system	X	X
- Fast forward video from system	X	X
- Pause video from system	X	X
- Ability to assign titles/numbers to video segments	X	X
- Ability to connect all text, audio/video and graphics segments	X	X
- Ability to designate video frame beginning and end points	X	X
Prompting		
- Menu-driven	X	X
- Menu by-pass	X	X
MANAGEMENT CAPABILITY		
Types of Records		
- Individual records	X	X
- Group records	X	X
- Individual responses	X	X
- On-line student registration	X	X
Methods Used		
- Management contained in authoring system	X	X
DOCUMENTATION/SYSTEM		
Manuals		
- Reference manual	X	X
- Tutorial	X	X

7. CONCLUSIONS

In addition to supporting the position taken by the Facilities Engineering Development (FESD) Branch that computer-aided learning (CAL) is an acceptable way of providing refresher and proficiency training to Air Traffic Control Electronics Technicians responsible for maintaining RAMP hardware, the study results provide the following key conclusions:

1. A CAL system based on standard "off-the-shell" microprocessor hardware is capable of delivering the range of training material to support the great majority of the RAMP training terminal objectives.

2. There are certain training tasks where safety requirements and extreme criticality considerations would determine that total reliance upon CAL would be unwise. It was suggested by the Raytheon RAMP subject matter experts that FESD would want to have job proficiency on these special tasks regularly demonstrated in a hands-on environment under co-worker, if not supervisory observation.

3. CAL with interactive video capability, preferably videodisc, is the recommended route to take in view of the desireability to simulate actuality in a significant number of training tasks.

4. Available standard I/O devices which support CAL do not impose in themselves threats of significance to the ergonomic suitability of the training station. Negative ergonomic factors could result, however, from the way the I/O devices are configured. Recommendations assuming that these negative factors are avoided will result from the design task to be undertaken next. Instructional design decisions such as use of colour, size of text, repetition of material, presentation of information, etc. are judged to be more important ergonomic issues than the physical characteristics of state-of-the-art I/O devices. The Literature Review dealt with these issues in detail.

5. The micro version of the NATAL authoring language looked at in the course of the study showed that it has sufficient capability to produce courseware requisite to the RAMP maintenance training requirement. Alternative authoring systems should be investigated primarily for reasons of ease of use, and cost-effectiveness.

SECTION
B

INPUT DEVICES FOR INTERACTIVE COMPUTER SYSTEMS

by

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June, 1988

TABLE OF CONTENTS

1 INTRODUCTION 1
  1.1 Principles For Selecting Input Devices 1
  1.2 Interaction Tasks With Computers 1
  1.3 Evaluation Criteria For Input Devices 2

2 DESCRIPTION OF INPUT DEVICES 4
  2.1 Keyboards 4
    2.1.1 Step Keys 4
    2.1.2 Test Keys 5
    2.1.3 Function Keys 6

3 POINTING DEVICES 7
  3.1 Direct Pointing Devices 7
    3.1.1 Touchscreens 7
    3.1.2 Lightpens 9
  3.2 Indirect Pointing Devices 11
    3.2.1 Mice 11
    3.2.2 Trackballs 12
    3.2.3 Joysticks 13
    3.2.4 Graphics Tablet 14

4 SPEECH RECOGNITION SYSTEMS (MOSTLY FROM SHNEIDERMAN, 1987) . 16
  4.1 Discrete Word Recognition 16
  4.2 Continuous Speech Recognition 17

5 COMPARISON OF INPUT DEVICES 18

6 CONCLUSION 27

REFERENCES 28

LIST OF FIGURES

Figure 2-1 Step Keys On a Keyboard 5
Figure 2-2 Text Keys On a Keyboard 5

Figure 3-1 The Touchscreen 8
Figure 3-2 Several Lightpens 9
Figure 3-3 Three Visions of the Mouse 11
Figure 3-4 The Trackball 12
Figure 3-5 The Joystick 13
Figure 3-6 The Graphics Tablet 14

Figure 5-1 Comparison of Many Devices for Positioning Speed 19-20
Figure 5-2 Time for Cursor Positioning As a Function of Locator and Error Locus 21
Figure 5-3 Effect of Target Distance On Positioning Time 22
Figure 5-4 Effect of Target Size On Positioning Time 22
Figure 5-5 Effect of Target Size on Error Rate Card 22
Figure 5-6 Path Completion Time For Arrow-Jump and Mouse Methods ... 24

LIST OF TABLES

Table 5-1 Meantime (Sec) to Perform Each Task For Six Subjects 22

1. INTRODUCTION

This paper describes and compares, from a human factors viewpoint, the different input devices that are mostly used for interacting with computers. The first section of the paper presents these input devices and lists their principal advantages and disadvantages. The second presents several experimental studies that compare the various input devices over a series of criteria. The goal of this work is to extract the most significant results from the literature and thus provide system designers with practical guidelines and criteria for selecting the best input device(s) for a given application.

Numerous documentation is available concerning input devices for dialoguing with computers. These will not be reviewed exhaustively, nor will their methdological aspects be closely examined, or their conclusions and recommendations be critically commented up on. This would be too long and would go beyond the goal of this paper. Rather, we will limit ourselves to the main reviews of the human factors literature, and take for granted the validity of the analysis and recommendations made by different authors.

1.1 Principles For Selecting Input Devices

The choice of an input device for communicating with a computer system must always be preceded by the following questions about the application:

1. What tasks are being performed with the system? What are their requirements in terms of speed, accuracy, error rate, variability over time, eyes and hands mobilization, etc?

2. In what context are they being performed? For instance, is it a heavy use environment where thousands of people may operate the system every day (e.g., an attraction center)? Is it in a cramped environment where space is critical (e.g., a submarine)? It is in a turbulent environment where movements may perturb the use of the device? Etc.

3. Who are the users of this system? Are they computer naive or knowledgeable? Are they fast typists or slow typists? Are they physically handicapped or not? Etc.

The issues raised by these questions represent very basic information for choosing the appropriate input device for an application.

1.2 Interaction Tasks With Computers

The tasks to be performed with the computer should be examined in terms of their requirements for the interaction with the machine. An examination of interactive graphics, based on the authors' experience with dozens of interactive systems, led Foley et al (1984) to conclude that there are six fundamental types of interaction tasks with computers:

- Select: the user chooses from a set of alternatives (e.g., command from a menu, a word from a file).

- Position: the user indicates a position on the interactive display, often as a part of a command to place an entity at a particular position (e.g., to create a drawing, position a window).

- Orient: the user chooses a direction in a 2-D or 3-D space (e.g., to rotate a symbol on the screen).

- Path: the user rapidly performs a series of position and orient operations (e.g, to follow a route on a map).

- Quantity: the user specifies a value (e.g., a number) to quantify a measure, such as the height of an entity.

- Text: the user enters, moves, and edits text in a two dimensional space. The pointing device indicates the location of an insertion, deletion, or change.

All these tasks have been performed with a keyboard in the past. Nowadays, new devices allow one to be more rapid and make less errors. These devices are described in the next pages.

1.3 Evaluation Criteria For Input Devices

A well-informed choice of an input device also requires some evaluation of the merits and deficits of each device. Several criteria may be used here. Here is the list proposed by Engel & Granda (1975) for determining "the best input device":

1. Control on keyboard which permits minimum hand movement. The user does not have to stop typing and move a certain distance to pick up or manipulate the cursor control.

2. Fast movement for short and long distances, is an obvious requirement. The cursor should be able to move across the screen rapidly. Positioning the cursor from any one point to any other point on the screen should not take more than 0.5 seconds for every 9-12 inches of travel in any direction.

3. Accurate positioning is critical and perhaps most important for graphic use, where the user wishes to place lines precisely, i.e., as near as possible to the practical resolution of the screen. Aiding accuracy is the ratio of control movement to display movement. When the ratio is greater than one, speed suffers, but the user can place the cursor with a much higher degree of accuracy.

Another component of accuracy concerns drift, the stability of the cursor when it has been placed. It must remain where it is positioned until moved by the user to another position. The control must have enough inertia so that it does not move of its weight, but not so much inertia that the user has to make a conscious effort to start it moving.

4. Freedom to displace from screen that is a control that can be operated by the user beyond an arm's reach of the screen; detachment will obviously help, if large screens are used. The operator will be able to back away from the screen, see a large view, and still have full input capability to the display. If the control is on the keyboard, this keyboard should then be separate from the display and be attached to it by a long enough flexible cable.

5. Extendability over a wide range of applications and environments. The cursor control should not be limited to one mapping of control movement to display movement. An example of this would be the user going from one-to-one input with every movement of the control mirrored exactly by the cursor to another method with perhaps a ten times reduction of the cursor for every unit of control movement.

Other criteria may also be important for various applications:

6. User's satisfaction is capital for the full acceptance of a device and the best efficiency.

7. Fatigue of the limbs that manipulate the device (e.g., arm, forearm, hand, knee, foot, etc.). It may cause unsatisfaction to users who spend several hours a day operating the device.

8. Learning time i.e. the time required to learn how to use the device effectively and be at ease with it. More than just a few seconds can prove unsatisfactory for the general public of a shopping center!

9. Space requirement is obviously critical in cramped environments (e.g., a cockpit) and often in normal offices.

10. Durability, which does not only pertain to the human factors domain, may be critical in heavy use environments (e.g., museums, attraction centers).

2. DESCRIPTION OF INPUT DEVICES

This section describes input devices that users manipulate to communicate with computer systems. The devices can be divided into three categories: keyboards, pointing devices, and speech recognition systems.

2.1 Keyboards

The keyboard is still the primary mode of data entry into the computer. It allows speeds up to 15 keystrokes per second (approximately 150 words per minute). Contemporary keyboards generally permit only one keypress at a time, although dual keypresses (SHIFT plus a letter) are used to produce capitals and special functions (CTRL plus a letter).

Despite different other layouts and the dedicated efforts of several devotees to replace it, the QWERTY keyboard has been recognized since 1971 as the standard keyboard by the International Standards Organization (Noyes, 1983). It is "the de facto standard layout for communications and computer interface keyboards". (Alden et al, 1972). This keyboard was developed a century ago, in 1866, by two Americans, C.L. Sholes and Glidden.

Apart from the alphabetical and numeric keys, keyboards also incorporate keys such as a space bar, Return, Backspace, Tab, Shift, Caps Lock, Num Lock, Ctrl, etc., plus one or several of the following groups of keys:

2.1.1 Step Keys

These keys, if there are any, correspond to the familiar five key cluster found on many keyboards (some keyboards have eight keys to simplify diagonal movements). Surrounding a central key are keys to move the cursor in each of the four directions (Figure 2-1). Pressing one of the horizontal keys moves the cursor one character along the line. Pressing a vertical key moves the cursor one line up or down. These keys have a typamatic (i.e., auto-repeat) feature, that is, repetition is automatic with continued depression. On many keyboards, the central key is a HOME key that causes the cursor to go to the upper left corner of the text when pressed.

Advantages:

- close at hand if user is typing (Engel & Granda, 1975);
- O.K. for text editing[1];

Disadvantages:

- movements of one space up/down or right/left only are possible;
- fine resolution difficult;
- cannot enter graphics.

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[1] No authors' name means the same authors as on the preceding line.

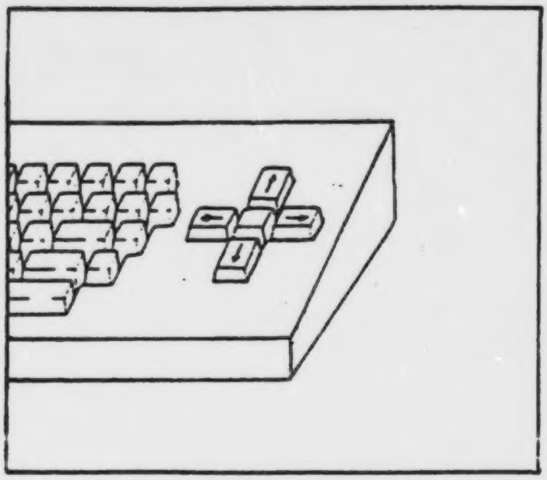

Figure 2-1. Step keys on a keyboard (From Janet, 1982).

2.1.2 Test Keys

These keys, if there are any, allow users to leap from one unit of text to another (Figure 2-2). For instance, in the study of Card et al (1978), depressing the PAR (paragraphy) key caused the cursor to move to the beginning of the next paragraphy, the LINE key, downward to the same position in the next line, the WORD key, forward one word, the CHAR (character) key, forward one character. Holding down the REV (reverse) key while pressing another key caused the cursor to move opposite the direction it would otherwise have moved. The test keys could also be used in a repeating mode.

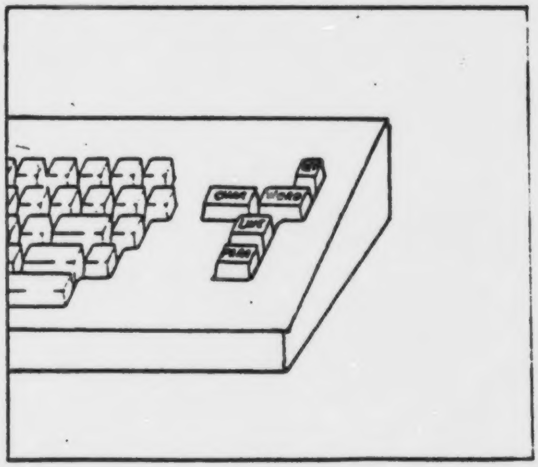

Figure 2-2. Text keys on a Keyboard (From Janet, 1982).

2.1.3 Function Keys

These keys, available on many keyboards, correspond to additional keys for special functions or programmed functions. They are often labeled F1 ... F10, or PF1 ... PF10. Their role consists in replacing a command name with a single keystroke.

Advantage:

- reduce keystrokes and errors, thus speeding work for novice or expert users (Shneiderman, 1978);

Disadvantages:

- users must remember them, learn about then from the screen, or consult an attachable plastic template;
- the purpose of each function key may not be apparent to some users;
- labels were often needed to remember the commands;
- users must remove their fingers from the home position on the keyboard, which is disruptive if movement between this home position and the function keys is frequent.

3. POINTING DEVICES

Pointing devices correspond to means of controlling a cursor on the screen. They can be grouped into those that offer (Shneiderman, 1987):

- direct control on the screen surface:
  - touchscreen
  - lightpen

- indirect control away from the screen surface:
  - mouse
  - trackball
  - joystick
  - graphics tablet

We briefly describe each of these devices and present their main advantages and disadvantages.

3.1 Direct Pointing Devices

3.1.1 Touchscreens

These devices allow the user to simply point to the screen with the finger (Figure 3-1). They have been built to operate on resistive, capacity, and acoustic principles.

Advantages:

- attractive because they allow director control touches on the screen (Shneiderman, 1987);
- do not require picking up some device;
- valued by system designers because
  - there are no moving parts
  - durability in high use environments is good
  - the price is relatively low.

Disadvantages:

- direct control on an upright screen can be fatiguing for the arms (Shneiderman, 1987);
- the user's hand obscures part of the screen;
- users must remove their hands from the keyboard;
- allows imprecise pointing due to thick fingers and parallax;

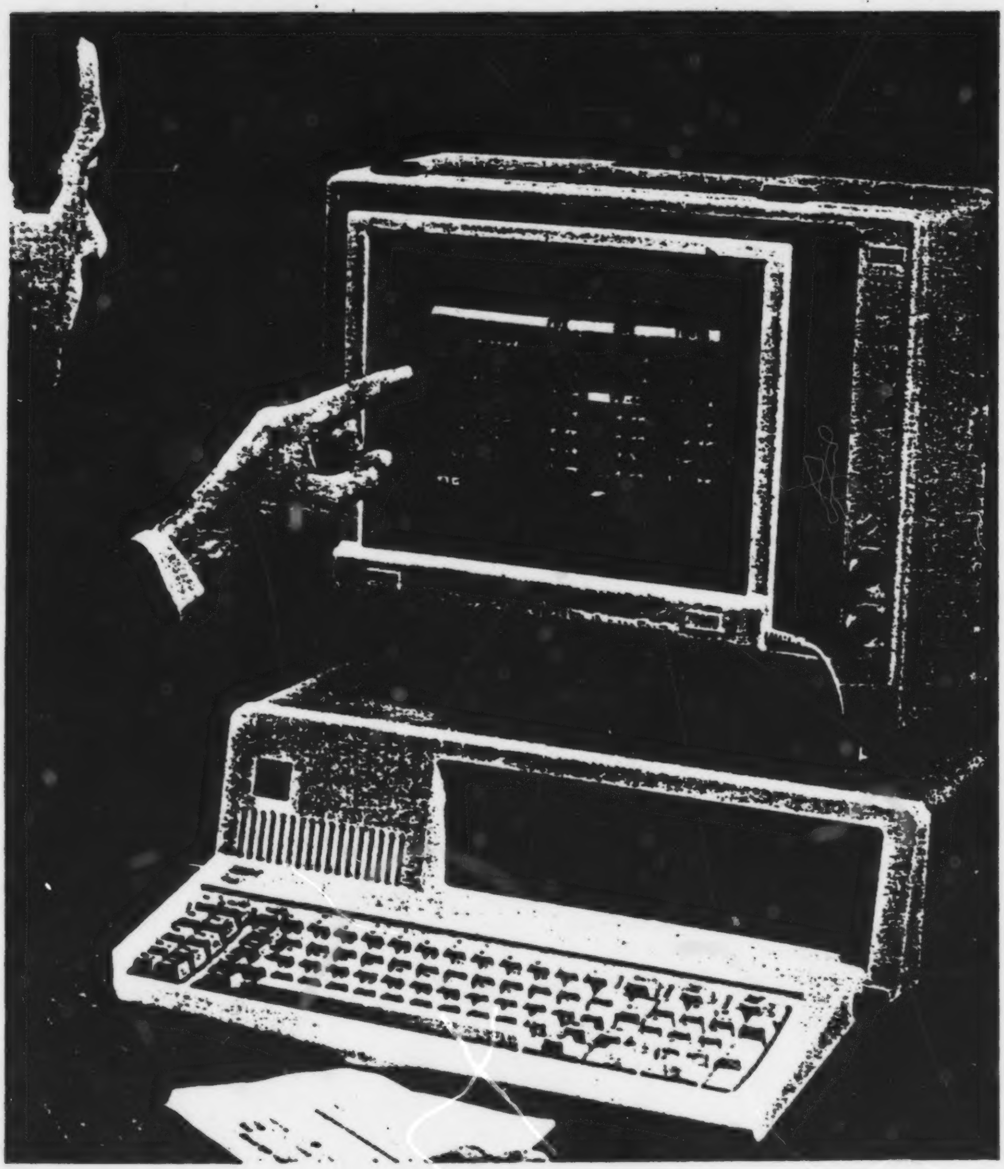

Figure 3-1. The touchscreen (from Shneiderman, 1987).

- most of the time, the software accepts the touch immediately denying the user the opportunity to verify the correctness of the selected spot. A two-touch strategy[2] or touch-in-touch-out pattern[3] may prove to be more appealing.

Comments:

- in high demand for applications directed at novice users in which the keyboard can be eliminated and touch is the only interface mechanism.

3.1.2 Lightpens

The lightpen is an early device that enabled users to point to a spot on a screen and perform a select, position, or other tasks (Figure 3-2). In fact, it could also be used to perform all six tasks presented above. Most lightpens incorporate a button for the user to press when the cursor is resting on the desired spot on the screen. Lightpens vary in thickness, length, weight, shape (the lightgun with a trigger is one variation, the selector pen is another), and position of buttons.

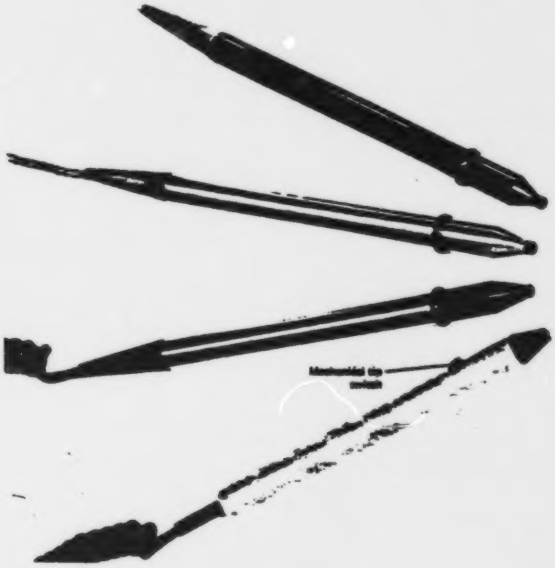

Figure 3-2. Several lightpens. One has mechanical tip switch; the others, capacitive (from Foley & Van Dam, 1982).

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[1] Touch once to produce a highlighted spot and touch again to execute the operation.

[2] The user's finger in contact with the screen surface produces a cursor that is dragged on the screen, then the execution occurs when the finger is pulled out.

Advantages:

- attractive because they allow direct control on the display (Shneiderman, 1987);
- fast for simple input (Engel & Granda, 1975);
- good for tracking moving objects;
- minimal perceptual-motor skill needed;
- good for gross drawing;
- low error rate if property implemented;
- efficient for successive multiple selections, if positions known;
- user does not have to scan to find a cursor somewhere on the screen;
- perhaps the most popular, truly interactive graphic instrument (Ritchie & Turner, 1975);

Disadvantages:

- direct control on an upright screen can be fatiguing for the arms (Engel & Granda, 1975; Shneiderman, 1987);
- the user's hand obscures part of the screen;
- users must remove their hands from the keyboard (Shneiderman, 1987);
- users must reach to pick up the lightpen;
- does not feel natural to user, like a real pen or pencil (Engel & Granda, 1975);
- contact with the computer may be lost unintentionally;
- lacks precision because of the pen's aperture, distance from the CRT (cathode ray tube) surface, and parallax;
- must be attached to terminal so the wire can be distracting
- glare problems if tube tilted to inconvenient angle;
- must flash the screen to find pen, if pointed to dark area;
- one-to-one input only;
- cumbersome to use with alternate, incompatible entry devices such as keyboard;
- tends to be used for purposes other than originally intended (e.g., key depression);
- care must be taken to provide adequate "activated" area around choice point;
- slow if many logical, scattered choices to be made.

The selector pen has the following characteristics:

Advantages: same as for the lightpen. In addition:

- it is not necessary to flash the screen to find it (Engel & Granda, 1975);
- it may not be connected if there is a built-in power supply;
- may have finer resolution if narrow beam of light emitted;

Disadvantages: same as for the lightpen, except that the following do not apply:

- may not have to be connected;
- screen does not have to be flashed.

3.2 Indirect Pointing Devices

These devices eliminate the hand-fatigue and hand-obsuring-the-screen problems. However, they must overcome the problem of indirection. Furthermore, the hand-off-keyboard and picking-up problems remain. Finally, they require more cognitive processing and hand-eye coordination.

The mouse, the trackball, and the joystick operate on the same basic principle of generating simultaneously x and y co-ordinate data by means of a mechanical coupling to mutually perpendicular potentiometers or shaft position encoders. They also have similar characteristics:

Advantages:

- very accurate with high resolution (Engel & Granda, 1975);
- expansion/contraction of cursor movement possible;

Disadvantages:

- must be attached, but not to display.

3.2.1 Mice

The mouse (Figure 3-3) is a small device which sits on the table to the right or left of the keyboard, connected by a thin wire. As it is moved over a plane surface, a cursor moves simultaneously on the display. It has become a widely used pointing device for interacting with computers. Many of its characteristics vary greatly from a mouse to another: the enabling technologies (physical, optical, or acoustic), the number of buttons, the placement of the sensor, the weight, and the size. This device was developed at the Stanford Research Institute in United States.

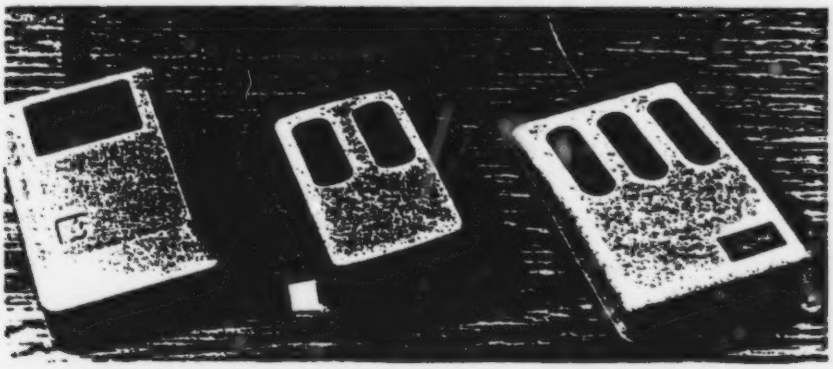


Figure 3-3. Three visions of the mouse with one (Apple Macintosh), two (Xerox Star), and three (PC Mouse for IBM PCs) buttons (from Shneiderman, 1987).

Advantages:

- the hand rests in a comfortable position (Engel & Granda, 1975; Shneiderman, 1987);
- includes space for control keys (Haller et al, 1985);
- buttons on the mouse can be easily pressed (Shneiderman, 1987);
- even long motions can be rapid;
- positioning can be very precise;

Disadvantages:

- must be picked up to begin work (Engel & Granda, 1975; Shneiderman, 1987);
- desk space is consumed;
- the mouse wire can be distracting (Shneiderman, 1987);
- pickup and replace actions are necessary for long motions;
- some practice is required to develop skill;
- must be used on a flat work surface, which can be impactical (Engel & Granda, 1975);

3.2.2 Trackballs

The trackball device is an arrangement whereby a ball (up to 7.5 cm in diameter) is free to be rotated by the hand (palm and/or fingers) within a hemispherical socket (Figure 3-4). It is firmly mounted in a desk or a solid box to allow the operators to hit the ball vigorously and make it spin. As the ball is moved a cursor is displaced on the screen.

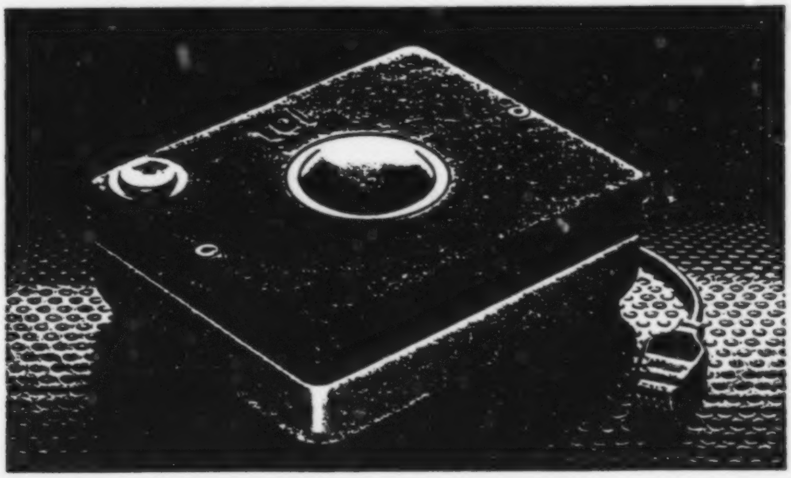


Figure 3-4. The trackball (from Shneiderman, 1987).

Advantages:

- can be attached to and used near the keyboard (Engle & Granda, 1975; Haller et al, 1985);
- excellent for three-dimensional rotation of object (not of cursor Engel & Granda, 1975);

Disadvantages:

- suitable only for cursor positioning (Shneiderman, 1987);
- inconvenient to have integrated "active" switch (Engel & Granda, 1975);

Comments:

- has been preferred in the high-stress world of air traffic control and in some videogames (Shneiderman, 1987);
- recent trackball developments include "active" switches.

3.2.3 Joysticks

The joystick is a small strain vertical gauge remote from the display on which the user applies some force in any direction to cause the cursor move in the appropriate direction (Figure 3-5). It originates from the automotive and aircraft industries. It varies greatly in length, thickness, displacement forces and distances, buttons and triggers, anchoring strategies for bases, and placement relative to the keyboard and screen.

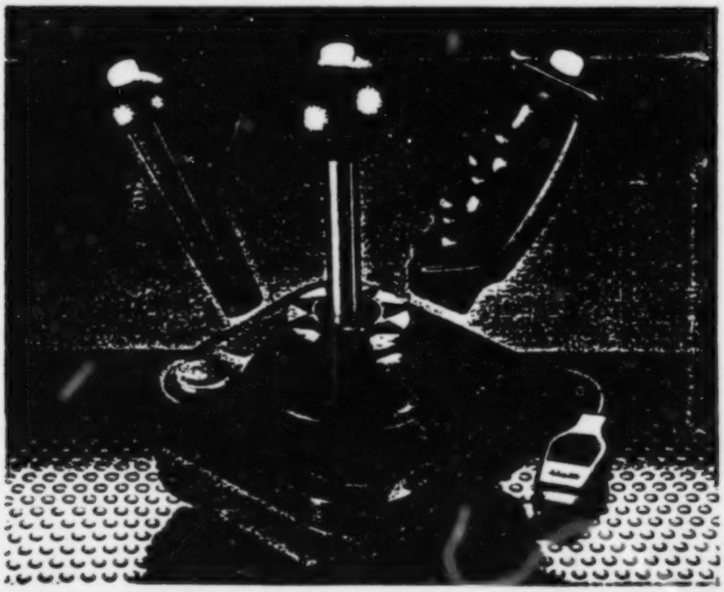


Figure 3-5. The joystick (from Shneiderman, 1987).

Advantages:

- appealing for tracking purposes, i.e. to follow a moving object on the screen, in part because of the relatively small displacements necessary to move a cursor and the ease of direction changes (Shneiderman, 1987).

Disadvantages:

- unless large joystick, inadequate control/display ratio with positional control. Ratio adequate with rate control (Engel & Granda, 1975).

3.2.4 Graphics Tablet

The graphics tablet concept is to have a touch-sensitive surface separate from the screen, usually flat on the table or in the user's lap (Figure 3-6). It can be operated by placement of a finger, pencil, puck, or stylus, using acoustic, electronic, or contact position sensing.

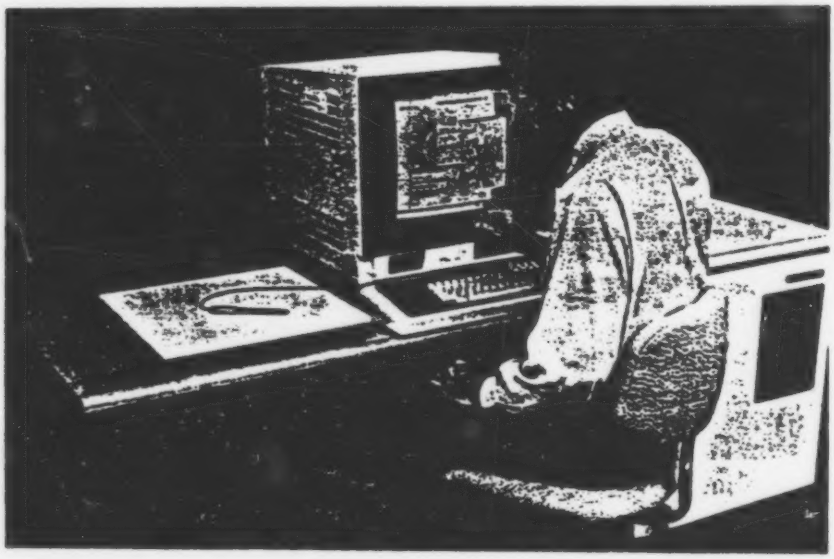


Figure 3-6. The graphics tablet (from Shneiderman, 1987).

Advantages:

- excellent for graphic entry (Engel & Granda, 1975);
- multi-purpose input device;
- expansion/contraction of cursor movement possible;
- minimal difficulty going from input to cursor control if character recognition is built into system and tablet used for other input;
- users work on horizontal surface (Engel & Granda, 1975; Shneiderman, 1987)

- permits a surface even larger than the screen to be covered with printing to indicate available choices, thereby providing guidance to novice users and preserving valuable screen space (Shneiderman, 1987).

Disadvantages:

- extra space required on worksurface (Engel & Granda, 1975; Haller etal, 1975);
- entering handwritten characters to be recognized by the system is very slow (fewer than 40 characters/minute) compared with typewriter entry (averaging 200 characters/minute) (Engel & Granda, 1975).

4. SPEECH RECOGNITION SYSTEMS (MOSTLY FROM SHNEIDERMAN, 1987)

Many people wish they could speak to computers and have computers speak to them. This would seemingly facilitate their interaction with machines by eliminating a great deal of data entry problems. Unfortunately, the reality is more complex than the visions or fantasies of many authors on this question. The technology is not quite here yet for free chatting with computers.

However, a dramatic progress in speech and voice manipulation devices has been made. Practical applications for specific tasks with specific devices are being designed to be more effective in serving the user's need to work rapidly with low error rates. The benefits to the physically handicapped are rewarding to see.

Speech technology has four components: discrete word recognition, continuous speech recognition, speech store and forward, and speech generation. We will only address the first two components which directly deal with data entry.

4.1 Discrete Word Recognition

"Devices to recognize individual words spoken by a specific person work with 90 percent to 98 percent reliability for vocabularies of from 50 to 150 words. Speaker-dependent training, in which the user repeats the full vocabulary once or twice, is a part of most systems. Speaker-independent systems are under development but are not yet reliable enough for commercial applications". (Also Foley et al, 1984).

Applications are successful for the physically handicapped or when at least one of these conditions exist:

- speaker's hands are busy
- mobility is required
- speakers eyes are occupied
- harsh (underwater) or cramped conditions preclude use of a keyboard.

Evalutions of speech recognition systems reveal problems with recognition rates, even for speaker-dependent training systems, when background sounds change, when the user is ill or under stress, and when words in the vocabulary are similar (e.g., dime-time). Current research efforts are devoted to eliminating or reducing these problems and show much promise for the future of such systems.

4.2 Continuous Speech Recognition

A continuous speech recognition system would certainly help to perform all sorts of tasks such as letter dictation, report composition, phone call scanning, etc. However, "... most observers feel that a commercially successful product will not be forthcoming in the next decade or longer", (Shneiderman, 1987). Recognizing the boundaries between spoken words turns out to be particularly difficult. In 1985, Kurzweil Computer Products announced an experimental system that could handle a 3000-word vocabulary for continuous speech. Testing is necessary to determine the real capacity of this system.

5. COMPARISON OF INPUT DEVICES

This section reviews several experimental studies that compare input devices over different variables. Comparing devices remains difficult because of three principal reasons (Janet, 1982):

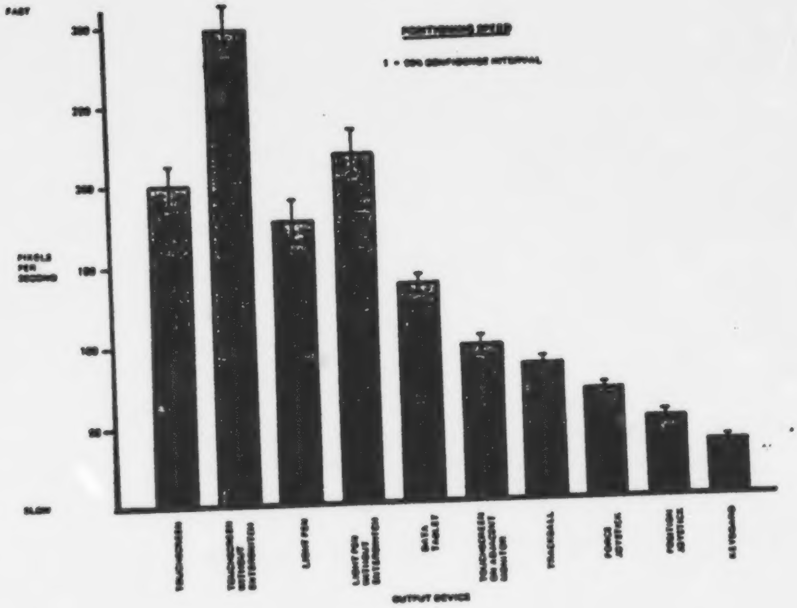
1. The experimental conditions of the studies vary, especially the tasks to be performed with the input devices.
2. There seems to be no study comparing all the devices to each other. Researchers have been comparing between two and seven devices at a time on a same task.
3. The dependent variables corresponding to the user performance vary from one study to the other. It may be speed of motion, accuracy, error rate, learning time, and/or subjects' opinions.

Furthermore, results are often controversial. Despite these difficulties, our goal here consists in extracting the most valid and well-accepted resutls. These should help designers to make well-informed choices of the most appropriate devices for their applications.

1. Multiple Devices Comparisons

Study #1: Albert (1982)

- Devices: Touchscreen/Touchscreen without enterswitch/Touchscreen on adjacent monitor/Lightpen without enterswitch/Data Tablet/Trackball/Force Joystick/Position Joystick/Keyboard.
- Task: to position the cursor on the display
- Results: (Figure 5-1)
  - (a) the touchscreen and the lightpen were the fastest devices, the joystick and the keyboard, the slowest ones;
  - (b) the touchscreen without enterswitch and the lightpen without enterswitich were the most inaccurate devices whereas the trackball and data tablet were the most accurate;
  - (c) a trackball was faster and more accurate than a joystick;
  - (d) a graphics tablet was slightly faster but slightly less accurate than a trackball;
  - (e) the touchscreen, the lightpen and the data tablet were the most satisfying for the subjects in terms of comfort, learning, and fatigue; the joystick and the keyboard were the least satisfying.



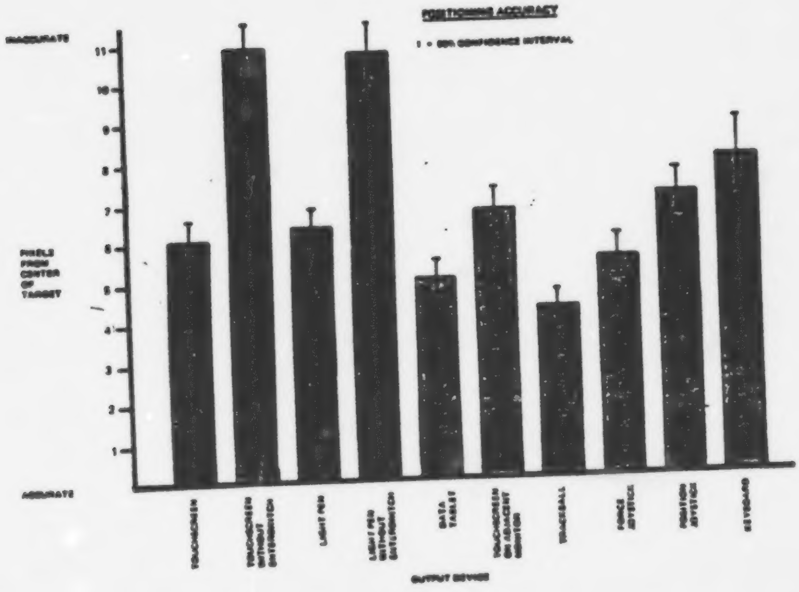


Figure 5-1 (Continued)

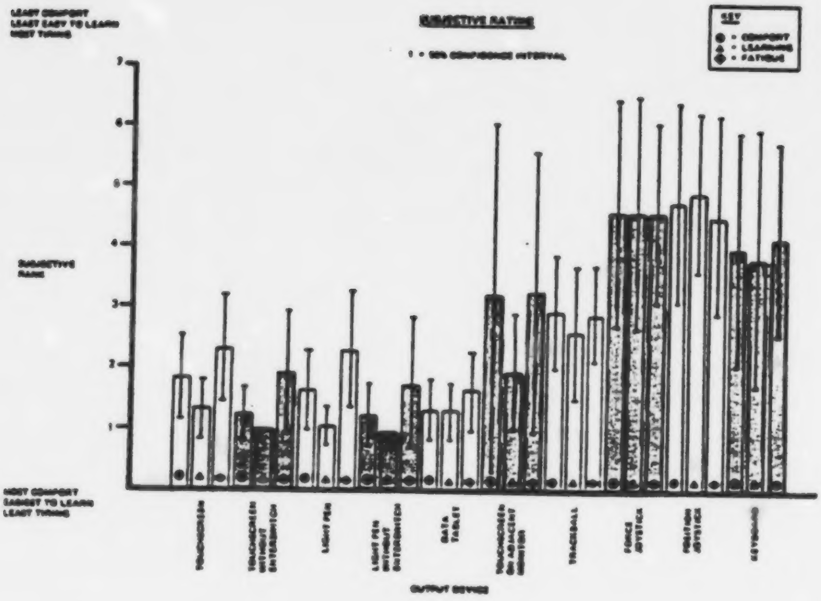


Figure 5-1. Comparison of many devices for positioning speed (a), positionging accuracy (b), and subjective ratings (c), (from Albert, 1982).

Study #2: Haller et al, (1985)

- Devices: Lightpen (or gun)/Graphic Table/Mouse/Joystick/Trackball/ Keyboard (cursor keys)/Voice Input.
- Task: correct typing errors (position the cursor on the erroneous character) in a letter already prepared on a word processor.
- Subject: N = 6
- Results: (Figure 5-2)
  - (a) the lightpen was the fastest device followed by the mouse, the graphic tablet, and the trackball, which were quite comparable and slighter better than the cursor keys;
  - (b) the voice input was the slowest device.

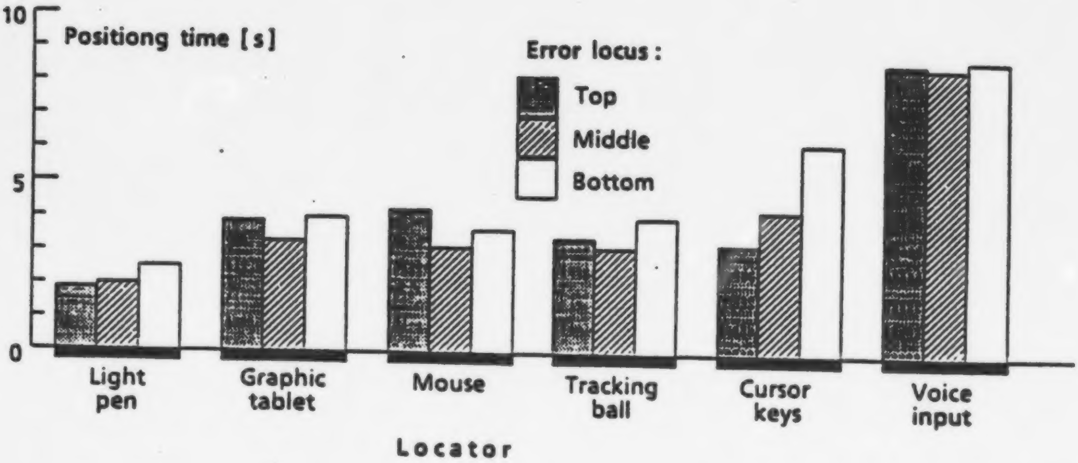


Figure 5-2. Time for cursor positioning as a function of locator and error locus averaged across correctors, typing errors, and Ss. (from Haller et al, 1984).

Study #3: Card et al, (1978)

- Devices: Mouse/rate-controlled isometric Joystick/Step Keys/Text Keys

- Task: select text on a CRT

- Subjects: 5 undergraduate students

- Results:

(a) The positioning time of the mouse is significantly faster than for the other devices. This is true at every distance (except 1 cm) Figure 5-3) and size combination save for single character targets (Figure 5-4). The position time increases rapidly with distance for cursor keys but only slightly for the mouse or joystick (see Figure 5-3). English et al, (1967) has already confirmed that the mouse was found to be faster than the joystick.

(b) The error rate of the mouse is significantly lower than that of the other devices for all target sizes (Figure 5-5).

(c) The rate of movement of the mouse is nearly maximal with respect to the information processing capabilities of the eye-hand guidance system.

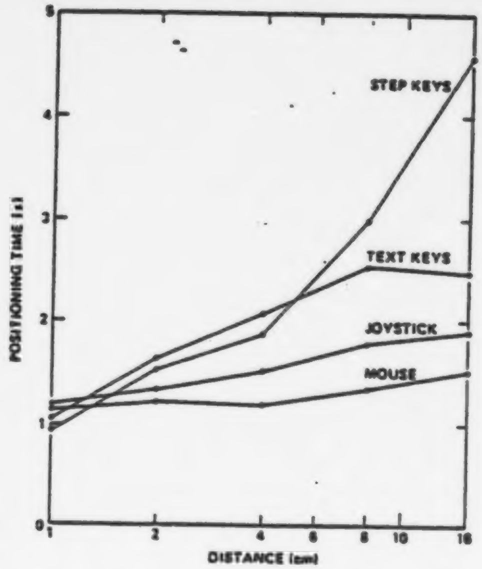


Figure 5-3. Effect of target distance on positioning time (from Card et al, 1978)

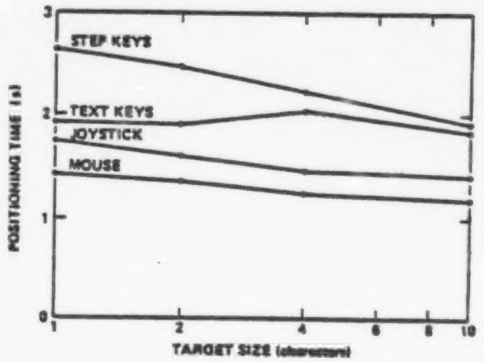


Figure 5-4. Effect of target size on positioning time (from Card et al, 1978)

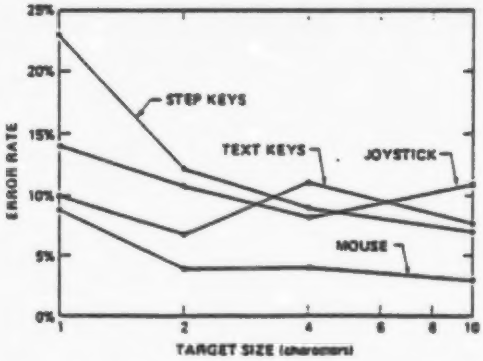


Figure 5-5. Effect of target size on error rate Card et al, 1978)

2. Three Devices Comparisons

Study: Goodwin (1978)

- Devices: Lightpen/Lightgun/Keyboard
- Tasks: a) Arbitrary cursor positioning: 10 target numbers are randomly positioned on the display: replace them with X's in numerical order, from zero to nine.

  b) Sequential cursor positioning: the display contained 10 letter M randomly positioned: replace each M with an X, moving from the top to the bottom of the display.

  c) Check-reading: read a paragraph of text, search for the 10 letter randomly positioned substitution errors, replace each one with the letter X.
- Subjects: N = 6
- Results: both the lightpen and the lightgun were four to five times faster than the keyboard for the arbitrary positioning task, and about twice as fast for the other tasks. (Table 5-1).

Table 5-1. Meantime (Sec) to perform each task for six subjects (from Goodwin, 1975)

Mean Time (Sec) For Six Subjects

	Lightpen	*Lightgun*	*Keyboard*
Arbitrary Positioning			
Trial 1	38.9	30.9	157.5
2	30.2	24.2	129.5
3	27.2	22.7	117.5
Mean	32.1	25.9	134.8
Sequential Positioning			
Trial 1	20.2	25.6	62.0
2	21.5	25.5	52.1
3	20.3	22.6	50.7
Mean	20.6	24.6	54.9
Check-Reading			
Trial 1	66.7	74.3	109.1
2	65.6	61.9	100.4
3	62.6	66.4	108.4
Mean	64.9	67.6	106.0

3. Two Devices Comparisons

Study #1: Ewing et al, (1986)

- Devices: Mouse/Step (arrow-jump) keys
- Task: select text (complete a path) in an interactive encyclopedia
- Subjects: 33 students
- Results:
  - (a) Arrow-jump keys had the quickest traversal times for paths with either short or long target distances (Figure 5-6)
  - (b) The arrow-jump method was also associated with more errors than was the mouse method.
  - (c) The step keys were found to have the highest subjective preference of the devices studies: more comfortable to use, more cotrollable, more enjoyable, and easier to use.

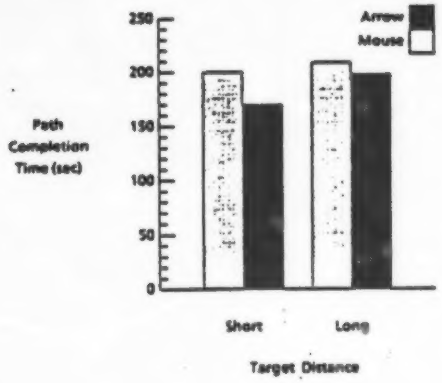


Figure 5-6. Path completion time for arrow-jump and mouse methods a function of average target distance of the traversed path (from Ewing et al, 1986).

Study #2: Murray et al, (1983)

- Devices: Step Keys/Speech recognition system
- Task: cursor movement on the display
- Result: cursor movement keys were twice as fast and more preferred

Study #3: Morrison et al, (1984)

- Devices: Keyboard (typed commands)/Speech recognition system (spoken commands)
- Task: correct online documents using the UNIX ed editor. For both typed and spoken commands, the user still had to type parameter string
- Duration: 4 on-hour sessions
- Subjects: 10 typists and 10 non-typists
- Results:

  (a) Typists preferred to use the keyboard whereas non-typists began with a preference for spoken commands but switched to favor using the keyboard by the end of the experiment.

  (b) No significant differences for task completion time or error rates.

Study #4: Legget & Williams (1984)

- Devices: Keyboard (typed commands)/Speech recognition system (spoken commands)
- Task: control an editor
- Duration: 90 minutes
- Subjects: 24 knowledgeable programmers
- Results:

  (a) The voice editor led to a lower task completion rate than the keyboard editor.

  (b) The keyboard entry produced a higher error rate.

Summary

In summary, some practical recommendations can be made regarding input devices:

- Direct input devices such as the lightpen or touchscreen are often the fastest but the least accurate devices. Therefore, when the targets are large and spread out on a large screen, the direct devices are strongly recommended.

- Pointing devices are faster than keyboard controls such as cursor movements keys but this result depends on the task. When a few targets are on the screen (2 to 10) and the cursor can be made to jump from one target to the next, then the cursor jump key can become faster than pointing devices.

- There is little evidence on the graphics tablet; the additional space provided on this device is appealing although the physical space requirements are a serious limitation in many applications.

- The mouse and the trackball are attractive when accurate pixel level pointing is needed.

- Lightpens shown no advantage over touchscreens, and the requirement to pick up the light pen is a serious disadvantage.

- Joysticks are attractive to game or aircraft cockpit designers, apparently because of the firm grip and easy movement, but they are slow and inaccurate for cursor positioning.

- At the present time, the voice input cannot be generally considered as beneficial.

6. CONCLUSION

The goal of this paper has been to described and compare from a human factors viewpoint the input devices that are mostly used for interacting with computer systems. First we described the main input devices and listed their principal advantages and disadvantages. Then we presented the results of several experimental studies that compared devices over different criteria.

"Asking "Which input device is best?" is much like asking "How long should a piece of string be?" The answer to both is: it depends on what you want to use it for"; (Buxton et al, 1985). This raises the importance of knowing the nature of the interaction tasks to be performed with the computer before selecting an input device. There is still more. Since it is the application which largely determines the suitability of a particular device the characteristics of the user population and of the particular context within which the device will be used must also be taken into consideration. Then the designer should be in a comfortable position for selecting the appropriate device(s) for a given application.

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SECTION

C

DESIGN RECOMMENDATIONS

by

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June, 1988

TABLE OF CONTENTS

1 DESIGN RECOMMENDATIONS 1

2 COMPUTER TERMINAL 2
2.1 Visual Display 2
2.2 Screen Filter 3
2.3 Keyboard 4
2.4 Other Input/Pointing Devices 7

3 WORKSTATION 8
3.1 Desk/Table 8
3.2 Chair 9
3.3 Document Holder 10
3.4 Foot Rest 11

4 WORK ENVIRONMENT 12
4.1 Position Of The Terminal 12
4.2 Lighting 12
4.3 Room Climate 14
4.4 Noise 14
4.5 Static Electricity 15

1. DESIGN RECOMMENDATIONS

The design recommendations presented below are mainly extracted from the document "Literature Review of An Assessment of the Ergonomy of a Training Work Station For Air Traffic Control Maintenance Technicians". They are presented with very few comments. For more information, the reader should consult the original document. These recommendations are concerned with several human factors issues that should be addressed for the design of well-suited work station. They aim at the best security, comfort, satisfaction, and performance of the operator.

2. COMPUTER TERMINAL

2.1 Visual Display (cathode-ray tube)

The following issues are not concerned with the software.

1. Two screens will be provided to the operator (decided on January 9, 1987).

2. The two screens should be located at the operator's convenience on the work surface. For instance, they could be positioned either side by side and parallel to each other or with a certain distance and angle between them.

3. The size of one monitor will be 19 inches diagonally (decided on January 9, 1987). The size of the second monitor will be either similar to or smaller than the first screen (common sizes are 13 or 15 inches).

4. The shape of the screens will be square (most likely) or rectangular.

5. The following aspects of the screens should be easily and rapidly adjustable (in a few seconds) by the operator:

   - height: the upper edge should be between 370 and 520 mm above the work surface, or at or below the height of the eyes;

   - orientation around the horizontal axis (5° foward and 20° backward): this adjustment would help eliminate reflections on the screens and provide a right angle to the operator visual angle.

   - orientation around the vertical axis to the convenience of one or two operators working together.

6. The minimum character height on the screens should be between 16' and 20' of an arc (20' is preferable), i.e. 3.1 - 4.2 mm. However, it should exceed 20', i.e. 3.0 mm, for a viewing distance greater than 50 mm.

7. The operator should be able to adjust easily and rapidly (in a few seconds) the eye-screen distance for both screens.

8. The operator should be able to adjust independently the luminance of the characters and the luminance of the screens' background. These adjustments could be done when the operator is sitting in front of the terminal.

9. A positive contrast, i.e. dark characters or images on a light background, is recommended by several authors, although this issue is often a matter of personal choice.

10. If a negative contrast is chose for the screen, the colour of the characters could be white, green, yellow, or orange. It is a matter of personal preference.

11. Character luminance should be in the range of 80 and 160 cd/m^2 and be operator adjustable. Character images should remain sharply defined at maximum character luminance.

12. The screen background luminance should be between 15 and 20 cd/m^2 under the appropriate office lighting conditions, and be operator adjustable.

13. The luminance contrast between the characters and the screen background should in the the range of 8:1 to 10:1 (optimal), and be operator adjustable.

14. The contrast between the screen background and other items in the working field (e.g., docments) should be in the range of 1:3 to 1:5.

15. A phosphore with a level of persistence such that the image does not smear when it is scrolled down, should be chosen.

16. The screens should be completely free of perceptible movement (i.e., flicker). The stabilization of the power supply. both as regards voltage and frequency, should be guaranteed. The refresh rate of the CRTs (cathode-ray tubes) should be 35 Hz if the persistence of the phosphore is high, 50 Hz if it is average, and at least 60 Hz if it is rather weak.

17. The colour of the console should be neutral and matt (e.g., grey). Black or white colour should be avoided.

18. The operational status of the VDTs (video-display terminals) should be made known to the operator at each moment (e.g., through a continuous light indicator).

19. The operator must be secured against electrical accident even when tampering with the VDTs.

20. The electrical supply cables and othe services to the VDTs and workplace should be adequately secured and concealed.

2.2 Screen Filter

Screens filter should be installed only if reflections on the screen cannot be eliminated through a re-arrangement of the work station.

1. For a normal office environment, the screen filter should consist in a thin-film or quarter wavelength layer. Other screen filters are also available; they can be ranked as follows: etching, polarization filter anti-glare treatment, micromesh filters, polarization filters.

2. Filters that make the screen completely dark and create excessive contrasts with the environment should be avoided as well as ones that excessively reduce character luminance and the contrast between the characters and the screen background.

3. The surface of the screen or screen filter should be regularly and carefully cleaned (to be free to dust, finger prints, and pencil points). An appropriate rag and cleaning solution should be available in each work environment.

2.3 Keyboard

1. Unless clearly contra-indicated by the task requirements, there should be only one complete keyboard for interacting with the display screen(s).

2. The keyboard should be detached from the display screen and joined to it by a flexible cables, long enough for the requirements of the user working style.

3. The profile angle of the keyboard should be between 5° and 15°, which is favourable for the position and motion of the hands and fingers.

4. The keyboard should be as thin as possible: the distance from its base to the home row of keys should not exceed about 30 mm.

5. The keyboard width should not exceed a maximum of 420 mm.

6. The keyboard should be free of movement over the work surface as well as heavy enough to stay stable through unintentional movements of the operator.

7 There should be a minimum of 50 mm between the space bar (which should be at the bottom of the keyboard) and the keyboard's edge for resting the palms of the hands.

8. Keytops should be square rather than circular because this shape provides a bigger target area for a given spacing between key centres.

9. The keytop size should be between 12 and 15 mm; the inter-centre spacing should be between 18 and 20 mm; the distance between the 2 edges should be between 3 and 6 mm; and the distance between 2 rows should be between 1 and 4 mm.

10. Keytop surfaces should be concave to aid the accurate location of the user's finger. The degree of concavity is important to keep specular reflections to a minimum.

11. Keytop surfaces should not be too roughened because this leads to accumulation of dust and grime which in turn obscure the keys' legends and is also aesthetically and perhaps hygienically unpleasant.

12. Keys' legends should be moulded into the keytop to resist wear and abrasion.

13. There should be a good contrast between the keys' colour and the keys' inscription colour, (e.g., light key with dark letters and numbers).

14. The keyboard's frame and keys should be of clear and neutral colour, and matt finished (black, white, or bright colours should be avoided). this minimizes reflection and provides a non-slip target.

15. The luminance ratio between the keyboard, the screen, and the documents should be less that 3:1 or 1:3.

16. The reflectance of the keyboard surface (not single key) should be between 0.4 and 0.6.

17. There should be an audible (click) and kinesthetic feedback from the keyboard. Feedback is important for accurate and rapid keying and self-detection of errors;

    - the user should be able to control the level of the audible feedback for more comfort;
    - the force required for key displacement should be between 0.25 and 1.5N;
    - the key displacement (travel) should be between 0.8 and 4.8 mm.

18. Legends should be uniform in size and as large as possible. They should not be smaller than the minimum acceptable character size on the screen, i.e. 2 mm, since ideally the distances eye-keyboard and eye-screen should be the same.

19. Unless clearly contra-indicated by the task requirements, the QWERTY keyboard layout which has become the universal keyboard layout for typewriter and terminal keyboards should be adopted.

20. The keyboard should be coffee-proofed.

In case this is important for the workstation designer:

21. The labels of the function keys should be standard symbols where they exist, (e.g., arrow keys for cursor controls).

22. Cursor control keys should be arranged so as to correspond to cursor movement.

23. Abbreviations of function key labels must be meaningful, simple, and consistent in order to be easy to remember. In practice, very few users can remember more than a few such functions and it is difficult to imagine how meaningful abbreviations could be written into the appropriate keytops.

24. If necessary, a look-up list of function keys should be provided when the users feel it would be of value to them.

25. When appropriate, all keyboards used by the same operator should be similar; all the function key labels and symbols should correspond to the same functions on other keyboards. This helps to prevent adaptation difficulties and errors.

26. If the operators are fast typists and if their task requires important data-entry, the keyboard they use should be provided with a n-key roll-over capability in order to store all the keystrokes that might be made in a burst and generate all the characters in the correct sequence.

27. If two or more keys are activated simultaneously, there should be a warning signal.

If functon keys are being used:

28. The number and type of function keys should correspond to the requirements of the task, and their arrangement should correspond to the sequences with which the task is carried out.

29. The number of function key should be kept low so that the user can easily access them, otherwise they won't be used in practice.

30. The keyboard should have some means to prevent critical errors: either by chord keying (the simultaneous depression of 2 or more keys), by double-pressing (the repeated action of a given key), or by sequential keystroking (the depression of 2 or more keys in a specific sequence).

31. All the critical command/function keys should be positioned separately form the more frequently used alphanumeric keys and less critical functions, or have other safeguards such as key lock, two-handed chord operation, or a higher required key pressure.

32. Colour, shape, position, and distance are effective ways of aiding the user in locating the correct function keys. Furthermore, they give a structure to the keyboard which is functionally desirable and aesthetically pleasing. Groups of keys with different functions must be of different colours.

33. The keyboard should have an UNDO (or UNDELETE) key to allow the user to undo any inadvertent operation, or undelete a killed item if it is later decided that the command was inappropriate.

34. The keyboard should have a facility to repeat certain characters or symbols continuously: either by having a separate repeat key which, when depressed, will repeat any other key instruction that is depressed at the same time, or by using typamatic keys which automatically repeat when depressed for more than a short period of time, typically half of a second. For most applications, only a few characters (e.g., underline symbol) need to be regularly repeated so that the selective use of typamatic keys may be sufficient.

If substantial quantities of numbers must be entered:

35. There should be a separate numeric keypad in addition to the standard numeric keyset (on the top row of the keyboard). The advantage is that block sequences of numbers can be entered single-handedly while mixed alpha-numeric data can be typed in a conventional manner.

36. The layout of the keys on the numeric keypad should be compatible with telephone pads (1, 2, 3 on the top row) since push-button telephones are increasingly being used in conjunction with VDTs.

2.4 Other Input/Pointing Devices

The other input/pointing devices that are considered consist of: touchscreen, lightpen, joystick, mouse, trackball, graphic tablet, and microphone (for speech recognition system). It is not decided yet which and how many devices should be used.

1. The operator should be able to position the input/pointing devices at his/her convenience on either side of the keyboard.

2. The mouse, joystick, keypad, graphic tablet, lightpen, or microphone should be joined to the display screen by a cable that is long enough to adapt to various working styles of the operators.

3. Enough room should be provided on the work surface for the rolling or photosensitive pad that is included with a mouse.

4. The keypad, the graphic tablet, and the trackball should be free of movements over the work surface.

5. The distance between the touchscreen and the operator as well as the height of the touchscreen be easily and rapidly adjustable by the operator.

3. WORKSTATION

3.1 Desk/Table

1. The work surface should be sufficient for:

   - possibly two persons working side by side (e.g., a senior and a junior technicians working together for a while);

   - the terminal and various components: 1 or 2 visusal displays, 1 or 2 keyboards, other input/pointing devices (e.g., mouse, keypad), a modem (built-in?), a printer, a box of paper for the printer, a microphone (?), a videodisc unit, etc.;

   - moving the input/pointing devices at one's convenience to get free space for working in front of the display screen;

   - devices: recorder, headphones, telephone, calculator, key pads, writing-pads, pencils, rulers, etc.;

   - storing, displaying, and using handbooks, reference manuals, documents, printouts, diskettes, look-up list function keys, etc.;

   - enough room on both sides of the keyboard or screen to position the work documents;

   - a document holder;

   - a desk lamp;

   - personal belongings;

   - miscellaneous objects: ashtray, coffee cup, etc.

2 The operator should be able easily to reach and operate the controls of the various input and output devices: keyboard, mouse (?), printer, videodisc unit, etc. The back row of the keys should be located at a distance of no more than 400 mm from the front edge of the desk. Simultaneously there should be a free area approximately of 60 mm depth in front of the keyboard as a resting place for the hands. This is a safeguard against the cutting action between the edge of the keyboard and the operator's wrist.

3. Ideally the desk height should be adjustable (650-750 mm) to satisfy different operator heights (about 95% are male and 5% are female). A desktop that permits the independent adjustments of the keyboard and the screen is more favourable because of its greater flexibility.

4. The desktop height should be in the range of 690-720 mm. With a keyboard thickness of 30 mm, the working level would thus be 720-750 mm. This height enables the operator to have the forearms and hands horizontal when the hands are on the home row of the keys.

5. The desk should be as thin as posible, i.e., 30 mm, to provide the operator with sufficient knee clearance in height (between 650-690) and with a convenient working level.

6. The underside of the desk should be free of obstructions such as desk frame spars that might be harmful or hurt the operator. It should be wide enough to enable the operator to turn unobstructedly (800 mm) or to enable two operators to sit side by side.

7. The desk should be deep enough (1000-1500 mm) to enable the operator to position the VDT in front of himself/herself and adjust the reading distance to his/her convenience (400-800 mm). This depth makes provision for knee (450 mm) and feet clearance (800 mm).

8. The desk should make provision for the physically handicapped on wheelchairs. This requires a special attention to the height, width, and depth of the desk underside.

9. The desktop colour should be matt finished: black or white colors, and any shiny coverings (e.g., glass) should be avoided. The reflectance from the desk surface should be kept to a minimum (0.4: optimum; 0.5: acceptance; 0.6: maximum).

3.2 Chair

1. The chair should have a five point base for increased stability.

2. The seat height should be adjustable between 450 and 500 mm (norms vary between 350 and 550 mm). The limbs of the body should be in the following position when the operator is sitting in a nearly upright position:

   - forearms and hands horizontal when the hands are on the keyboard;
   - thighs horizontal;
   - feet flat on the floor.

3. The back rest should be adjustable in height and angel for pelvic andlumbar support. If there are tension springs, their tension should be adjustable if the back rest is mobile in relation to the seat, or if the seat is mobile in relation to the chair pivot.

4. Dimensions of the chair should be as follows:

   - seat depth: 350-450 mm;
   - seat width: 380-400 mm;
   - back rest height: 480-500 mm;
   - back rest width: 280-320 mm;
   - back rest tilt: 2° forward, 15° backward.

5. The seat and back rest covering should be rought textured for a better friction, and flexible to distribute the pressure and avoid pressure spots. The covering should permit air circulation over the surface of the skin.

6. The front edge of the seat should be cruved down to prevent it from cutting into the thighs in the sitting position.

7. The chair should have castors and/or a rotary facility if the operator has to move and/or turn around frequently (e.g., for accessing different work surfaces). These castors should be self-locking for chair stabilty (specially important on non-carpeted floor). They should be hooded for preventing any damage to the operator's clothes or shoes.

8. Arm rests that prevent the chair from fitting under the table should be avoided because the operator could be too far from the keyboard and not use the back rest of the chair.

9. All the adjustments should be capable of being easily, rapidly (a few seconds), and safely made from a seated position by the operators themselves. The mechanisms should stay fixed when the chair is in the diesired position.

3.3 Document Holder

(to be provided to the technicians if many documents are being manipulated)

1. The document holder should be designed so as to take into consideration the characteristics of the documents to be used (e.g., weight dimensions) and the manipulations to be done with them (e.g., additon, correction, turn pages frequently, follow the text with the finger). Accordingly, the document holder should be sufficiently long, wide, and strong to maintain the document in place despite the manipulations.

2. The operator should be able to position the document holder as desired, i.e., on the right or left side of the screen, or between the screen and the keyboard. Ideally, the document holder should be next to, at the same plane as the display screen. This way the reading distance is the same as for the screen, and the line of sight is at right angle to the plane of the document holder.

3. The document holder should be adjustable in height, depth, and inclination (about its vertical and horizontal axes).

4. The adjustments should be made easily, rapidly (a few seconds), and a safely by the operators. The mechanisms should stay fixed once the document holder is in the desired position.

5. The document holders should have a bottom lip and/or a magnetic or other type of clip (depending on users' preference) to secure the position of the document.

6. The document holder should be matt finished.

3.4 Foor Rest

(attention: wheelchairs)

1. A foot rest should be provided if the operator is small and cannot put his/her feet flat on the floor when sitting at the terminal, or has blood circulations problems in the legs.
2. The foot rest should be adjustable in height (0-50 mm) and in inclination (0°-15°) for more comfort.
3. The adjustments should be made easily, rapidly (a few seconds), and safety by the operators. The mechanism should stay fixed once the foot rest is in the desired position.
4. The foot rest should cover the entire leg area. Its width-depth should be about 400 mm (300 mm minimum).
5. The footrest should be covered so as to enable comfortable movement of the feet without slipping.
6. The foot rest should stay stable when one is moving the legs or feet. Some authors recommend that is be secured to the floor or desk to prevent any sliding. Attention should be given to the use of wheelchairs.

4. WORK ENVIRONMENT

4.1 Position Of The Terminal

1. The visual display should not be backed against a wall. Rather there should be an open area behind it to keep the maximum flexibility for adjusting the reading distance (800 mm for some operators) and to allow the operator to have a viewing distance of at lest 6 m when not looking at the screen or table.

2. Terminals should be oriented such that the operator and the screens are not facing the window. The line of sight of the operator should be parallel to the windows. Since windows are the most important source of the reflections on VDT screens, they should be on only one side of the room.

3. Terminals should be oriented such that the line of sight of the operator be parallel to the luminaires. This orientation eliminates shadow on the work surface.

4. Operators must not be facing shiny objects or annoying lamps.

5. The number of VDTs installed in a room should be as small as possible, and evenly distributed over the office area because of possible temperature and noise problems.

6. Terminals should be far enough for air diffusers to protect the operators against air draughts on the head, neck, shoulders, and arms. (These parts of the body are more sensitive to air draughts).

7. Operators should be able to get in and get out of the work place easily, rapidly, and safely. No electrical supply cables or other services to the VDT and work place should be in their way. There should be provision for emergency situation.

4.2 Lighting

1. VDT (video-display terminals) working areas should be illuminated with 300 to 500 lux luminance. The lighting level should be adjustable by the operators themselves.

2. Fluorescent lamps with the colour "neutral white" are those which are compatible with daylight and may be generally recommended. However, subjective preference should have the proirity.

3. All lamps should have the same colour temperature because different temperatures can produce an irritating twilight effect. Lighting should be uniform in the entire visual field.

4. To provide a more favourable light distribution, glare shielding of the lamps should be achieved (with filters or diffusers). The prismatic pattern and grid pattern types are more generally preferred. In all cases unshielded fluorescent lamps (i.e., those in which the tubes are visible with a viewing angle of 45% or less) must be avoided.

5. The luminaires should be installed in a direction which is parallel to both the viewing direction of the VDT operators and the windows in order to minimize the perception of glare. However, to prevent too uniform a structure in the layout of the work room, this recommendation needs not be rigidly adhered to.

6. The question of whether or not the luminaires should be recessed into the ceiling depends, among other things, on the likelihood of problems caused by glare. When the lamps are recessed, the luminance of the ceiling is less than when they protrude or are suspended below ceiling level thus permitting illumination of the ceiling itself.

7. In order to avoid stroboscopic effects between the display screen and the fluorescent lamps and between the lamps themselves, the use of a "duo-circuit arrangement"[1] is recommended, particularly in smaller work rooms. In larger rooms it is sensible to couple neighbouring lamps with different phases to treble the effective flicker frequency.

8. If there are windows in the work room, drapes or blinds should be installed to protect against glare, especially in areas where terminals are located near windows or can be reached by light rays. Draps or blinds are also important at night for preventing the reflection of illuminated object inside the room.

9. The drapes of blinds should be bright, plain, and with a reflectance of more than 0.5 in order to match that of the wall surfaces inside the room. They should be opaque enough to stop the light rays and one must be able to close them completely. In large windows they should be divided in sections in order not to block entirely the view of the exterior.

10. The darkening of the room and the total shielding of the natural light should be avoided because in general it is psychologically unacceptable. Total or partial darkening of the room can only be recommended if the work being carried out requires such an environment.

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[1] In this type of circuit, a phase difference is introduced in the voltage supply to each lamp so that the maxima and minima of the light flux from the lamps no longer coincide.

11. If work requires reading documents: Operators who wish to have an individual lighting on the work surface because the general lighting does not accommodate them even after adjustments, should be provided with individual desk lamps. This lighting should be operator adjustable in intensity (about 500 lux), position, orientation, and be provided with glare shields.

12. The reflection factors in the work office should be as follows: floor between 0.2 and 0.4; wall between 0.3 and 0.8; ceiling between 0.6 and 0.9; work surface: 0.4; keyboard: 0.15 to 0.17; keys between 0.2 and 0.7.

13. The luminance ratio in the central field of vision (e.g., between the keyboard and the screen, between the keys and the paper) should not exceed 1:3 (1:1 would be theoretically ideal), and the luminance ratio in the peripheral field of vision should not exceed 1:10.

4.3 Room Climate

1. These air conditions should be maintained stable during the working hours in the office environment:

   - temperature between 21° and 23°, 26° and 28° during the hot summer days;
   - relative humidity between 50% and 55% (authors' recommendations vary between 50% and 79%);
   - speed of air movement less than .1m/sec.

2. The thermal emission from the VDTs should be taken into account when calculating the air conditioning requirements of the room. A VDT may emit a significant amount of heat. Equipment with low thermal emission should be purchased whenever possible.

3. The individual operator and their neighbours should be protected against the heat dissipated by VDTs and toher equipment. The draughts around the neck, shouldres, and arms, as well as local hot spots (e.g., under desks, in corners, etc.) should be avoided.

4. Operators should have the possibility to adjust the temperature, humidity, and speed of air movements to their convenience.

4.4 Noise

1. The operators should be able to work in a sufficiently quiet place (55 dB(A) in task areas requiring a high level of concentration, and 65 dB(A) in routine task areas).

2. The equipment noise levels (e.g., fans, power supply from the VDT, other equipment) should be no more than 5 dB(A) greater thant he background noise level. The noise in the VDT room should not be affected by external noise sources (e.g., neighbouring rooms, or the outside world).

3. High freqency tones should be eliminated because they are particularly stressing.

4. If there are printers or teletypes: where possible, they should be removed from the immediate work place (and located in a special room), or encircled with sound panels. Where impossible, they should be covered with a hood through which one can read without uncomfortable postures.

4.5 Static Electricity

1. Special precautions should be taken to safeguard against the discharge of static electricity to the VDT chassis. It could be through treatment of the floor, carpets, furniture, etc. This problem is unpleasant and could be the cause of dermatitis according to some authors.

SECTION D

DEVELOPMENT OF A TRAINING WORKSTATION FOR AIR TRAFFIC CONTROL MAINTENANCE TECHNICIANS - DESIGN AND MOCK-UP BUILDING

By

Rutenberg Design Inc.

June, 1988

TABLE OF CONTENTS

1. INTRODUCTION 1

2. DESIGN METHODOLOGY 2

3. CONCEPTS 3
   3.1 CAL-DESK 3
   3.2 CAL-TREE ....
   3.3 CAL-COON 4

4. CONCEPT EVALUATION 5

5. CAL-STATION 6

6. FINAL MOCK-UP 7

7. DESCRIPTION OF FINAL DESIGN 8
   7.1 Use 8
   7.2 General Description 9
   7.3 Detailed Description 9

APPENDIX A - Preliminary Drawings

APPENDIX B - Photographs of Development Process

1. INTRODUCTION

As part of the project team to develop a Computer Assisted Learning Station for Air Traffic Control Maintenance Technicians, RUTENBERG DESIGN INC. was responsible for the design of the station and its presentation in a full scale simulated mock-up form.

The design was based on information provided and requirements established by the following studies, which were completed as a first phase of this project: "Literature Review of an Assessment of the Ergonomy of a Training Work Station for Air Traffic Control Maintenance Technicians" by SYPHER:MUELLER International Inc. in associations with Scoioscope Inc., Jean-Marc Robert, Ph.D. and Thomas Communications Ltd., March 1986; "Ramp Task Analysis Report and Computer-aided Learning Media Study" by Thomas Communications Ltd., August 1986; and "Design Recommendations for a Training Work Station for Air Traffic Control Maintenance Technicians" by Jean-Marc Robert, Ph.D., January 1987.

2. DESIGN METHODOLOGY

The objective of this design process was to transform ergonomic user requirements and technical and operational requirements into a three-dimensional workstation.

This workstation would provide technicians with course material using stat-of-the-art computer technology and specially designed human interface components.

Based on studies completed by the project team as a first phase, the design team of RUTENBERG DESIGN INC. set out to design and present different approaches to solve this problem. These approaches were shown to the project members in the form of small concept models.

In addition to the information provided, the design team visited the technician's offices and workshops in Dorval, Quebec and held meetings with the Director of Technicians, Mr. Harvey Devost and several senior technicians to analyze their workload and working procedures. The following was the result of these investigations:

- Serious consideration has been given to transforming all reference material presently in the form of manuals, into a digitized format available from one central data base to all technician stations across the country. The timeframe is expected to be 2-5 years. This could result in the need for a second monitor.

- The only manual which will still be used is one per each technician for keeping his notes and adding those required during the refresher course. This would eliminate the need for a document holder.

- The environment for such a workstation was considered by the Dorval group as either a typical office with 9-10' ceilings, fluorescent light, carpet and office components such as filing, desks and tables, or an electronic workshop with 12' ceiling, low noise, tiled floor and fluorescent lights. Space itself seemed to be of secondary importance, but the ability to get components through doors for relocation was an important aspect.

- The time for a refresher course was considered to be between 20-25 minutes.

Three concepts were developed and described as CAL-DESK, CAL-TREE and CAL-COON. In each concept a different emphasis was placed on the interface between the technician and the workstation components. The following is a description of the concepts.

3. CONCEPTS

3.1 CAL-DESK

CAL-DESK is a workstation, based on an adjustable desk structure with all components being integrated. This allows for a compact arrangement of a single stand-alone unit as well as for a multiple station lay-out. The technician operates from an available office working chair which is according to the requirements, adjustable in height, back-angle and seat depth. The chair has a five star base and armrests.

All height, angle and distance adjustments for the monitor, the desk, the keyboard, the footrest, the trackballs, the telephone, the document holder and the light are made from a seated position.

The same applies for a person who would work from a wheelchair. An inviting opening in front of the station provides generous space for a typical office chair and wheelchair access.

The monitor can either be used in an upright position with the keyboard or in an inclined position as a touch screen. The required keyboard (CAA-2-234,4/NATAL) is located in front of the technician, independantly adjustable in height and angle. One trackball is located on each side of the keyboard for left and right handed persons. A separate document holder is located on top of the monitor with its own adjustable task light. Vertical louvers on each side provide limited sound isolation and prevent visual distraction for the technician. The ambient light is controlled by an overhead diffuser with an adjustable front panel to prevent glare. The appearance of this workstation relates to the modern computer-equipped office environment.

3.2 CAL-TREE

CAL-TREE is a cylindrical free-standing structure, its shape completely independent of its location in an office or workshop space.

A strong vertical post carries all components which come off like branches and are individually adjustable in height, distance and angle. Depending on the complexity of each technician station or substation in the country, the number of components can be increased or decreased, therefore making it a very flexible system. Wiring of all components is concealed in two snap-on channels along the column for easy installation and modifications. Two monitors are provided in vertical position, on displaying the course material and the other reference and supporting material.

Two independent armrests are provided on the keyboard panel, which all for ideal arm support.

The working space is enclosed by a curved visual screen and acoustic side panels which provide privacy and prevent distraction.

An overhead diffuser provides its own indirect light in case the environmental light sources are too weak. An additional movable curtain prevents reflection on monitor screens and controls. A task light underneath the main monitor supplies light to the keyboard area.

The station is wheelchair accessible over a small ramp around the mainbase.

The appearance is characterized as an advanced, non-conventional design.

3.3 CAL-COON

CAL-COON is a self-contained capsule, completely independent of the environment for sound, light, temperature and air.

The interior consists of two parts, one is the built-in component side, the other a built-in seat and control side.

The component side has two monitors side-by-side, one being the course monitor, the other the reference monitor.

Their angle and distance to the viewer is adjusted by a remote control panel. All operations including keyboard, trackball and chair positions, are controlled from this panel, which folds down from the side, in front of the seated technician.

All ambient controls, e.g. for light, colour intensity, sound input and output, air and temperature are located on the same control board.

A light diffuser is located in the ceiling of the unit, providing its own light or using that of the office.

A built-in stereo system and microphone provide the highest sound quality for telephone and telecom communications.

A pale coloured translucent panorama window allows relaxation and a sense of contact with the outside.

When the door is closed, a beacon indicates that the unit is in operation and should not be distrubed.

This concept is not easily accessible for a wheelchair user.

The appearance of this station has a highly experimental, futuristic character.

4. CONCEPT EVALUATION

On February 13, 1987 all project members met to evaluate the three different concepts. The result of this evaluation is interpreted in Table 8.1. The members agreed that the concepts were generally conforming with the ergonomic requirements and the general parameters established for this workstation.

Although several characteristics were not present in one concept or the other, additional innovative design features had been included, which went beyond the ergonomic requirements, such as trackballs left and right, fully controlled audio and visual environment and an electronically adjustable seat.

The CAL-DESK and CAL-TREE concepts were rated highest, the CAL-COON concept lowest.

The CAL-DESK seemed to provide the best work desk lay-out and the CAL-TREE the best component flexibility. The totally controlled and enclosed CAL-COON concept seemed to be too advanced for the present requirements and was not wheelchair accessible.

The project members concluded that a fourth model be presented which would combine the best characteristics of both concepts, CAL-DESK and CAL-TREE.

5. CAL-STATION

This fourth model was presented on February 27, 1987 and accepted by the project team as fulfilling the ergonomic requirements. The concept was assessed from the users point of view, based on the expert knowledge of Ron Shingles of Transport Canada and on interviews with technicians by Rutenberg Design Inc.

CAL-STATION was highlighting the following particular characteristics:

- increased space for manuals 11" x 26" (technicians own schematics);
- decreasing importance of keyboard as input device, possibly being eliminated in the future;
- two innovative sliding trackballs for left and right hand use with finger controls;
- two multi-directional screens, one 13" colour monitor for course material, one 17-19" colour monitor for reference material;
- space for writing pad at left and right side of desk;
- increased storage space left and right underneath desk top; and
- fully adjustable and reclinable table tops.

The evaluation of this model is interpreted in Table 8.2.

A decision was made to move the mock-up stage.

6. FINAL MOCK-UP

The design team then proceeded to verify full dimensional interfaces with components such as monitors, trackballs, footrest, keyboard, light controls, etc. by building these components in cardboard and simulating operations.

After final relationships between the user and the components had been established, shop drawings were prepared and a mock-up was built in wood, metal and plastic to simulate a complete work station in its appearance, volume, colour and size.

This final design was presented on May 20, 1987. The members concluded that this mock-up was a fair representation of the fourth model, representing the required design principles and therefore should be accepted unanimously as the final design.

It was then decided that this mock-up would be delivered to Transport Canada in Ottawa for further evaluation, enhancing its use by reinforcing the table to be equipped with a real monitor and a CPU and adding headphones to the system.

7. DESCRIPTION OF FINAL DESIGN - CAL-STATION

7.1 Use

The training workstation is to be used by one ATC maintenance technician. The adjustable worksurface, monitors, lighting and seating allow for the work station to fit the user, rather than the user adapting to the work station.

Any distractions in the environment such as bright, glare and background noise are controllable. Thereby, creating a more pleasant, comfortable and productive learning environment.

The workstation is a clearly defined area, offering semi-privacy, yet not allowing the user to feel confined in an enclosed space. A typical office environment and possibly an electronic workshop are areas where the station is likely to be situated.

7.2 General Description

CAL-STATION consists of a U-shaped wall system which supports the basic components of the work stations.

The ceiling structure, worksurface and monitors are all components firmly secured to the structural frames of the walls, but can be easily detached for replacement and maintenance.

The walls house all electrical wiring which can be accessed for servicing by removing the exterior panels.

The easy assembly of the system allows for rapid installation. CAL-STATION is to be identified as a learning place, not to impose, but to blend into any existing office environment.

The overall appearance is that of an open, light structure. The walls offer visual privacy to the user as well as create an acoustic barrier from the surrounding environment.

The form is tapered to visually reduce its ovearall mass, as well as permitting two or more units to be placed next to one another, forming a multiple work station and thereby minimizing floor space.

The colours relate to the technical environment and are defined according to function.

The exterior is beige which blends itself into various office environments. On the inside, beige is also, being neutral and light, it doesn't disturb the user while working at the station.

The dark blue trim contrasts with the neutral panels, defining the shape of the work station.

The worksurface is mauve, a neutral colour, with low reflectance. All controls, and handles are magenta. A brighter colour, visible-defining elements that can be adjusted by the user. It also indicates proper and safe positioning of hands for moving components.

The overall size of CAL-STATION was based on the space required for a technician to comfortably perform all tasks and necessary movements of monitors, yet not be wider than existing standard office desks. It must also fit into an area with a low ceiling (of approx. 8' - 10" height).

7.3 Detail Description

The workstation is designed to fit the user. The adjustable chair, worksurface, the positioning of the monitors, and the control of lighting are all features of the work station which make this possible.

Seating

The starting point of the work station is with the chair. The operator sits down and adjusts the chair before beginning to work at the station. The chair has a five point base, a fully adjustable seat height (45 - 50 cm), adjustable backrest, height and angle, providing necessary lumbar support and with or without armrests, with castors on carpeted surfaces, glides on the tiled floors.

Worksurface

The overall size and shape of the worksurface area is determined by the arrangement and layout of the basic items used by one maintenance technician (to function at the learning centre).

This includes:

- one technician's manual, fully open and placed directly in front of the user (in relation to the corresponding monitor);
- a writing pad or notebook that can be positioned to either the left or right hand side of the worksurface (for left or right handed users);
- the keyboard (alphanumeric) is located directly above the technicians manual, still within arms length reach (it is used to activate programs by pushing one or two keys only, not for typing sentences over a long period of time);
- two trackball hand controls (for left or right handed users), to be positioned on each side of the worksurface, between the technicians manual and the not pad.

The front edge to the worksurface is soft moulded, which is soft for the arms and body to touch.

It also acts as a bumper to protect against office chairs and wheelchairs. A raised lip prevents books and pencils sliding from the worksurface.

The main feature of the work surface is its adjustability (to fit the user). It can be raised and lowered between 65-75 cm, making it accessible for wheelchair users. The slope can be adjusted between 0° (horizontal) to an inclination of 15°.

The trackball hand control is an input device used to activate the computer learning programs. Two hand controls (for left and right handed users), which can be moved to a comfortable operating position, are placed shoulder width apart on the worksurface.

The trackball hand control fits comfortably into the palm of one's hand. To each side is a push button, when squeezed together, releases the unit allowing it to slide and change positions.

The trackball acts as a cursor for the graphics monitor. It can be rotated in any direction using only fingertips.

The control functions are colour-coded push buttons positions directly above the trackball, at an angle for easier identification to the touch.

The hand controls are secured to movable tracks on the worksurface, the definite locations are easily found by every user. Portable units may be misplaced or stolen. A conventional mouse requires a large clear area of the worksurface to function, whereas the trackball hand control occupies only a small area. If the one hand unit is not in use it can be stored out of the way allowing room for a technician's manual to be placed fully open and directly in front of the user.

The main operating controls for the work station are grouped together to form a control panel, which is found in the upper right hand corner of the worksurface, easily reached and visible to every user.

The operating controls are:

- a main switch which turns on the entire system;
- a control for ambient light with variable intensity;
- a light sensor which activates ambient lighting to the mimimum required; level;
- a volume control for the headset (if the software provides audio output);
- a switch to control the height of the worksurface; and
- a switch to adjust the inclination of the worksurface.

Symbols and graphics indicate the functions for each control.

The upper left hand and corner of the worksurface is used as a pencil holder and as a coffee cup holder, preventing any spillage near the keyboard or on any documents. This area is not a prime worksurface area and within easy reach from a sitting position.

Storage space is provided underneath the worksurface to both the left and right hand sides. The worksurface is not to be used for storing large items, such as extra manuals, notebooks and writing pads. The storage trays are visible and easily reached from the sitting position, and do not interfere with the users legroom.

Foot Rest

The footrest is adjusted by applying force with one's feet to the desired height and angle. The height can be adjusted between 0-5 cm, the slope between 0° and 15°.

The footrest covers the entire foot area with a depth of 32 cm.

Monitors

Two visual display terminals are used by the technician at the learning work station, both are adjustable.

One is a small monochrome monitor used for reference, and the of other is a large high resolution colour monitor used for graphics, with anti-reflective screen.

The user controls the position and orientation of the monitors by pulling forwards, pushing backwards, raising, lowering, rotating and tilting the monitor.

By changing the viewing distance to the screen and its positioning, it is possible to reduce eyestrain, fatigue and eliminate glare. The monitors are secured to arms that pivot from the rear wall panel (allowing their position to be interchanged, left and right). The brightly coloured handles to each side of the monitor are used to adjust the angle (5° forwards - 20° backwards) and the height (top edge of screen is 37 - 52 cm above worksurface). They also act as protective bumpers. To the front, the handle is used to adjust the viewing distance (40- 80 cm) to the screen, and to rotate the monitor about its vertical axis.

Telephones

All models of telephones and intercom systems (such as "Harmony", "Philips", "Standard" ...) can be accepted by and secured to an adjustable arm that pivots from the rear wall of the work station. The telephone is within reach and does not occupy valuable space from the worksurface. A handle to the front allows the user to pull out the telephone when needed, and push it back when not in use.

Headset

A headset is necessary when an audio mode is part of the computer learning program. The headset and its attaching cables are not to interfere with the view of the screen when being used or when stored away. It is stored and attached by a flexible cable directly above the user's sitting position. The volume control is found on the control panel and within easy reach.

Lighting

The abmient light and task light levels are controlled by the user. The existing light from the environment, such as daylight, overhead fluroescent light and so on, can be partly controlled.

The elements of the system which control lighting are:

- the ceiling diffuser;
- front and rear diffusers;
- ambient light;
- task lights; and
- vertical louvers to each side of the worksurface.

The ceiling diffuser is constructed from a translucent material (90% translucency) positioned at 45° angle, the harsh overhead light is softened and distributed more evenly, reducing the shadows in the work area. Also, it controls glare to the monitor screens.

The front and rear diffusers are also made from a translucent material, controlling incoming light directly in front of the operator, but especially from behind the operator, where any light source causes glare on the monitor screens.

Both diffusers are adjustable, handles to each side allow operator in a standing position to move the diffusers.

Ambient light for the work station is automatically activated by a light sensor found on the worksurface providing the minimum light level (300 - 500 Lux) required to perform any task.

A light switch that controls intensity is found on the control panel. The light is reflected towards the ceiling, providing a soft, evenly distributed light on the worksurface area, eliminating any shadows. The light can be rotated in any direction, but must be operated form a standing position.

Task lights extra lighting to the worksurface area without creating any glare on the monitor screens. Two task lights, one to each side of the worksurface are easily reached from a seated position. Attached to a flexible neck, they can be placed in any position and orientation.

To each side to the work surface area can be found vertical louvers, which can be adjusted (rotated) in any direction, therefore controlling incoming side light.

The louvers also offer privacy, without making the user feel enclosed or confined within the work station space.

Table 8.1 Evaluation

REQUREMENTS				CAL-DESK	CAL-TREE	CAL-COON
WORKING SPACE	DESK	DESK HIGHT AND ANGLE ADJUSTMENT		3	3	0
		DESK SURFACE FOR MANUALS	DIMENSION	0	2	0
			USER INTERFACE	0	2	0
		DESK SURFACE FOR WRITING PADS	DIMENSION	1	1	0
			USER INTERFACE	2	2	0
		COFFEE SPACE LOCATION		1	1	1
	MONITOR	MONITOR - USER INTERFACE		3	3	3
		MONITOR - MANUALS RELATION		3	1	0
		MONITOR - MONITOR RELATION		0	2	3
		USE AS A TOUCH SCREEN		3	2	2
		GLARE PREVENTION		2	2	3
	INPUT DEVICES	TRACKBALL - USER INTERFACE		2	2	2
		KEYBOARD - USER INTERFACE		3	3	3
	TELEPHONE	TELEPHONE - USER INTERFACE		3	3	3
	INTERCOM	INTERCOM - USER INTERFACE		3	3	3
	DOCUMENT HOLDER	DIMENSION		1	0	0
		LOCATION		2	0	0
		ADJUSTABILITY		2	0	0
	STORAGE	DIMENSION		0	0	3
		LOCATION		0	0	3
	FOOTREST	FOOTREST - USER INTERFACE		3	3	3
	CHAIR	CHAIR - USER INTERFACE		3	3	3
LIGHTING	AMBIENT LIGHT	AMBIENT LIGHT CONTROL		2	2	3
	TASK LIGHT	TASK LIGHT CONTROL		2	2	3
WHEELCHAIR ACCESSIBILITY				3	1	0
APPEARANCE	MODERN			3	1	0
	ADVANCED			1	3	3
	EXPERIMENTAL			1	3	3

ADDED QUALITIES (ESTABLISHED THROUGH DESIGN PROCESS)			CAL-DESK	CAL-TREE	CAL-COON
MODULARITY (MULTIPLE SET-UP)			3	1	2
REQUIRED PRIVACY	VISUAL		2	2	3
	AUDIO		1	2	3
TOTAL ENVIRONMENTAL CONTROL	VISUAL		0	0	3
	ACOUSTIC		0	0	3
CONTACT WITH ENVIRONMENT	VISUAL	DIRECT	2	1	0
		INDIRECT	0	0	3
	AUDIO	DIRECT	3	3	0
		INDIRECT	3	3	3
INCREASE AND DECREASE NUMBER OF COMPONENTS			0	3	0
USE FOR LEFT/RIGHT HANDED TECHNICIANS			3	3	3
ACCESS FOR SERVICE AND REPAIRS			3	3	2
MANUFACTURING AND COST					

Evaluation Results

	CAL-DESK		CAL-TREE		CAL-COON	
	R	A	R	A	R	A
NONE (0)	6	4	6	3	12	3
POOR (1)	5	1	5	2	1	0
GOOD (2)	7	2	9	3	2	2
EXCELLENT (3)	11	5	9	4	14	7
SUB-TOTAL	52	20	50	20	47	25
TOTAL	72		70		72	

R - REQUIREMENTS
A - ADDED QUALITIES

Table 8.2 Evaluation

REQUIREMENTS				CAL-STATION
WORKING SPACE	DESK	DESK HIGHT AND ANGLE ADJUSTMENT		3
		DESK SURFACE FOR MANUALS	DIMENSION	3
			USER INTERFACE	3
		DESK SURFACE FOR WRITING PADS	DIMENSION	3
			USER INTERFACE	3
		COFFEE SPACE LOCATION		3
	MONITOR	MONITOR - USER INTERFACE		3
		MONITOR - MANUALS RELATION		3
		MONITOR - MONITOR RELATION		3
		USE AS A TOUCH SCREEN		3
		GLARE PREVENTION		2
	INPUT DEVICES	TRACKBALL - USER INTERFACE		3
		KEYBOARD - USER INTERFACE		2
	TELEPHONE	TELEPHONE - USER INTERFACE		3
	INTERCOM	INTERCOM - USER INTERFACE		3
	DOCUMENT HOLDER	DIMENSION		0
		LOCATION		0
		ADJUSTABILITY		0
	STORAGE	DIMENSION		2
		LOCATION		3
	FOOTREST	FOOTREST - USER INTERFACE		3
	CHAIR	CHAIR - USER INTERFACE		3
LIGHTING	AMBIENT LIGHT	AMBIENT LIGHT CONTROL		2
	TASK LIGHT	TASK LIGHT CONTROL		3
WHEELCHAIR ACCESSIBILITY				3
APPEARANCE	MODERN			3
	ADVANCED			2
	EXPERIMENTAL			1

ADDED QUALITIES (ESTABLISHED THROUGH DESIGN PROCESS)			CAL-STATION
MODULARITY (MULTIPLE SET-UP)			3
REQUIRED PRIVACY	VISUAL		2
	AUDIO		1
TOTAL ENVIRONMENTAL CONTROL	VISUAL		0
	ACOUSTIC		0
CONTACT WITH ENVIRONMENT	VISUAL	DIRECT	2
		INDIRECT	0
	AUDIO	DIRECT	3
		INDIRECT	3
INCREASE NAD DECREASE NUMBER OF COMPONENTS			2
USE FOR LEFT/RIGHT HANDED TECHNICIANS			3
ACCESS FOR SERVICE AND REPAIRS			3
MANUFACTURING AND COST			

Evaluation Result

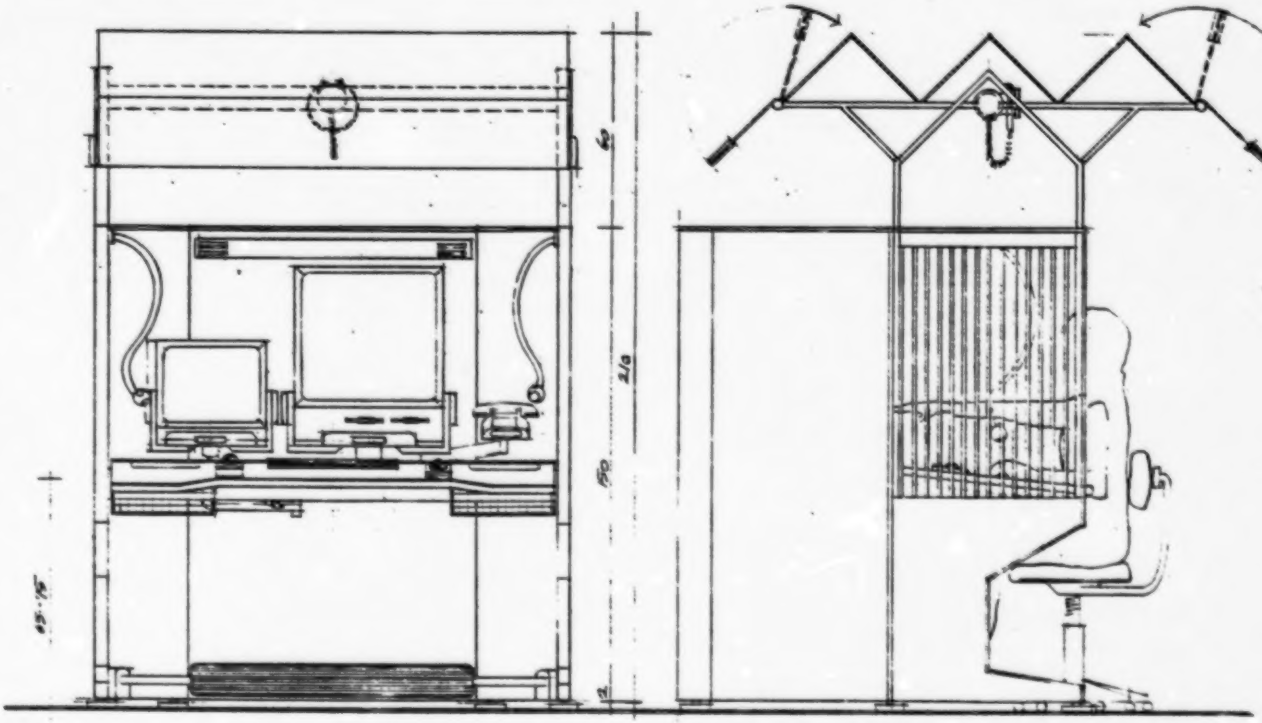
	CAL-STATION	
	R	A
NONE (0)	3	3
POOR (1)	1	1
GOOD (2)	5	3
EXCELLENT (3)	19	5
SUB-TOTAL	68	22
TOTAL	90	

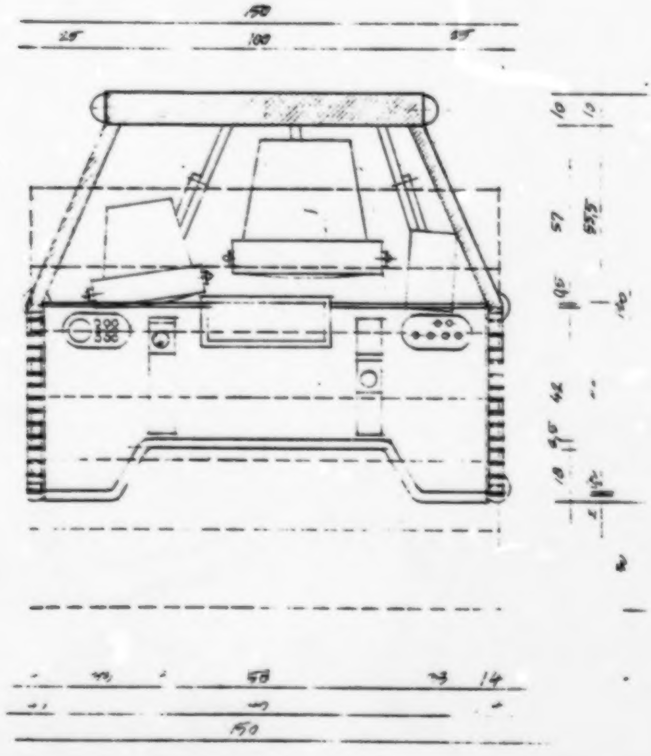
R - REQUIREMENTS

A - ADDED QUALITIES

APPENDIX A

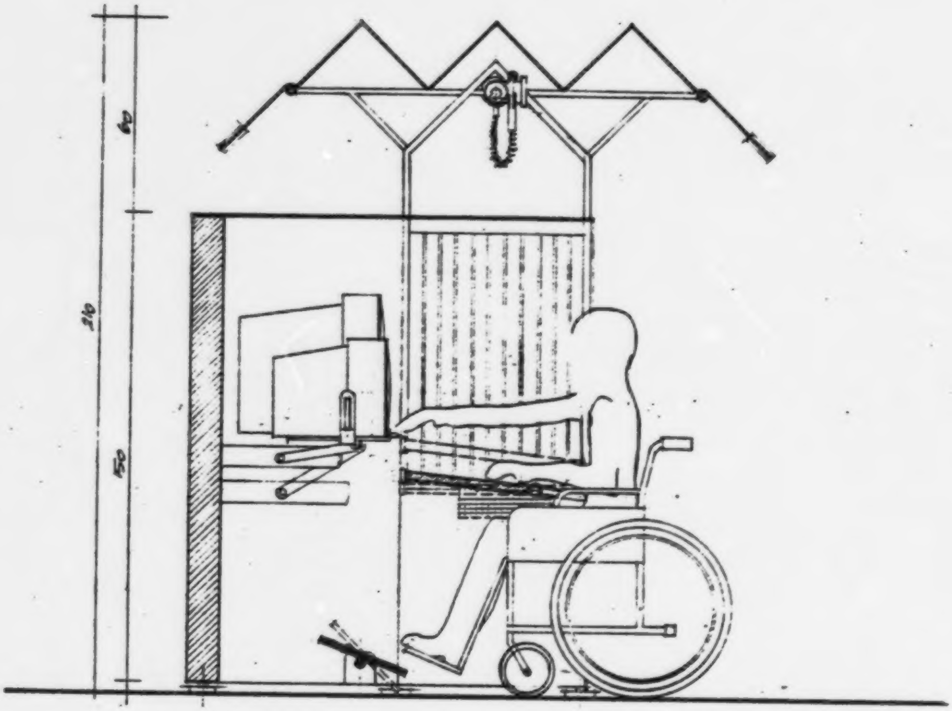
PRELIMINARY DRAWINGS

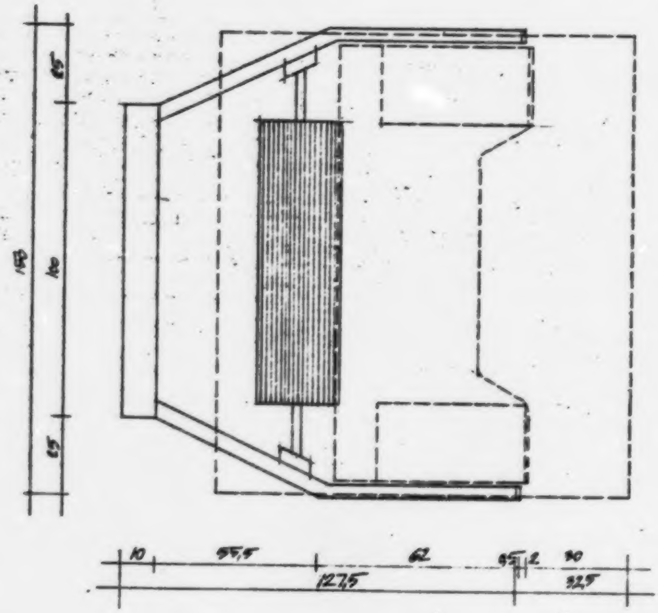




RUTENBERG DESIGN INC.

Projet / Project	CAL STATION
Titre / Title	ASSEMBLY
Conçu par / Designed by	MAJA BARTULOVIC
Date / Date	MAY '85
Échelle / Scale	N/A





RUTENBERG DESIGN INC.

Projet / Project CAL STATION
Titre / Title SECTIONS
Conçu par / Designed by MAJA BARTULOVIC
Date / Date MAY 1987
Échelle / Scale N/A

APPENDIX B

PHOTOGRAPHS OF DEVELOPMENT PROCESS

TABLE OF FIGURES

Figure 1 Various Concepts B-1
Figure 2 CAL-DESK B-2
Figure 3 Document Holder B-2
Figure 4 CAL-TREE B-3
Figure 5 Components Branch Off B-3
Figure 6 Diffuser and Curved Panels B-4
Figure 7 CAL-COON B-5
Figure 8 Built-In Components B-5
Figure 9 Adjustable Worksurface B-6
Figure 10 Access for Wheelchair User B-6
Figure 11 Left and Right Trackball Controls B-6
Figure 12 Designer Verifying Components B-7
Figure 13 Preliminary Mock-Up B-7
Figure 14 Reference Material B-8
Figure 15 Technician's Manual B-8
Figure 16 Building of Mock-Up B-9
Figure 17 Final CAL-STATION B-10
Figure 18 Monitors, Headphones and Manual B-10
Figure 19 Workspace Lay-Out B-11
Figure 20 Control Panel B-11
Figure 21 Adjusting Telephone Location B-12
Figure 22 Use and Position of Keyboard B-12
Figure 23 Adjusting Monitor for Distance B-13
Figure 24 Monitor Adjustment for Correct Angle B-13
Figure 25 Position of Sliding Trackball Controls B-14
Figure 26 Left Hand Side B-14
Figure 27 Right Hand Side B-14
Figure 28 Ambient Light B-15
Figure 29 Task Light B-15
Figure 30 Adjustable Footrest B-16
Figure 31 Adjustment Floor Leveling Device B-16
Figure 32 Presentation and Evaluation of Final Design B-17

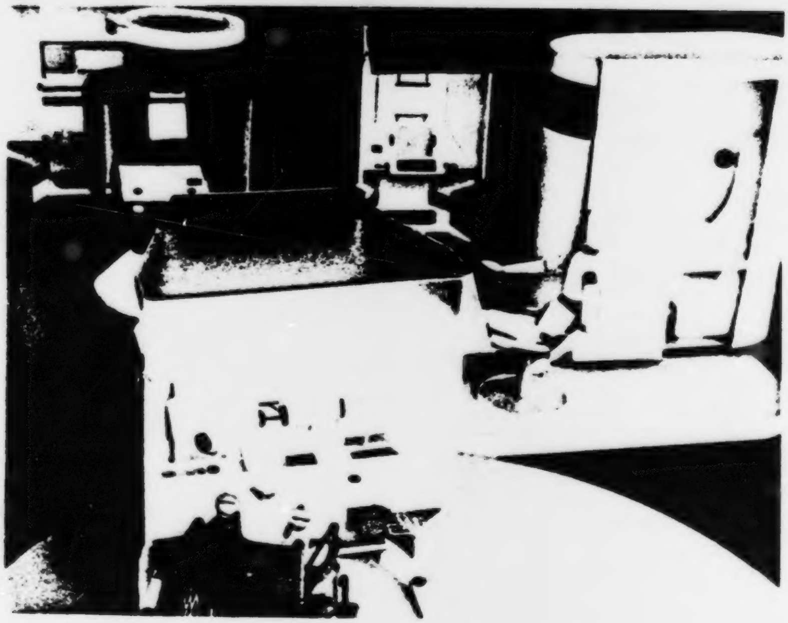


Fig. 1

Various concepts in small model form

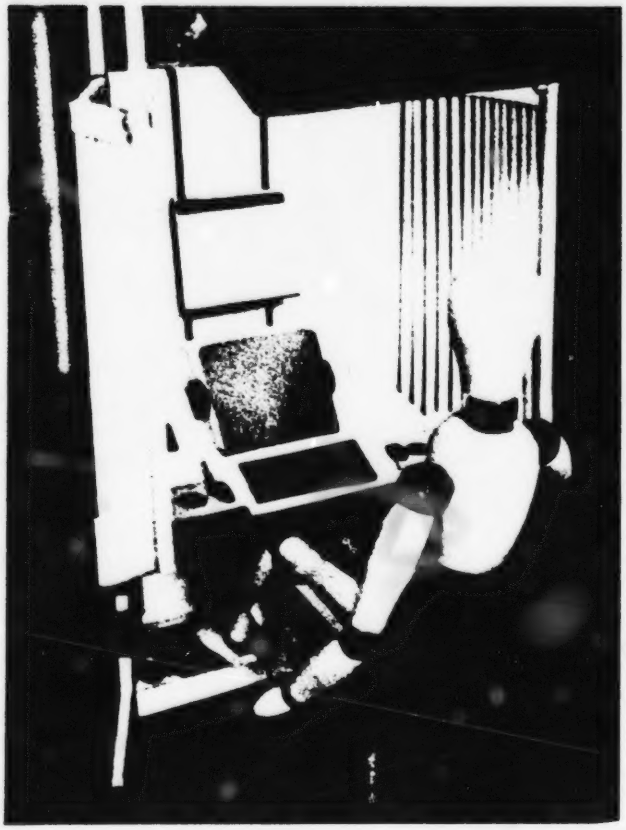


Fig. 2
CAL-DESK **workstation concept with**
vertical louvers, reclinable keyboard
and upright/touch-screen monitor

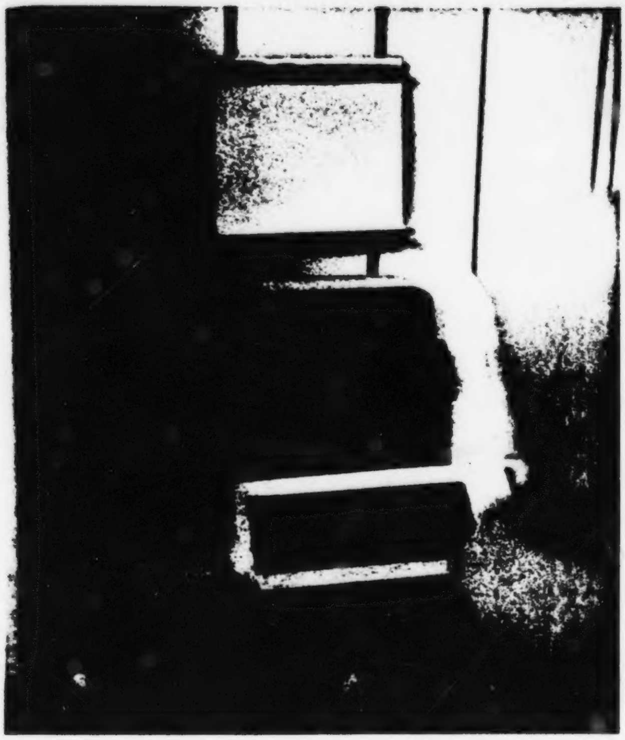


Fig. 3
Document holder on top of monitor
with adjustments on tracks

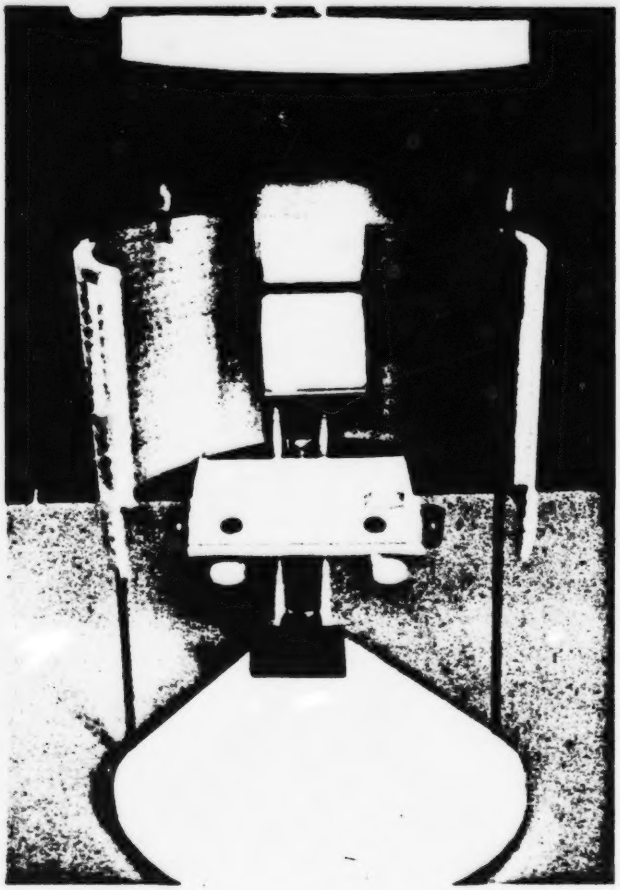


Fig. 4

CAL-TREE, cylindrical shape with curved acoustic and visual panels

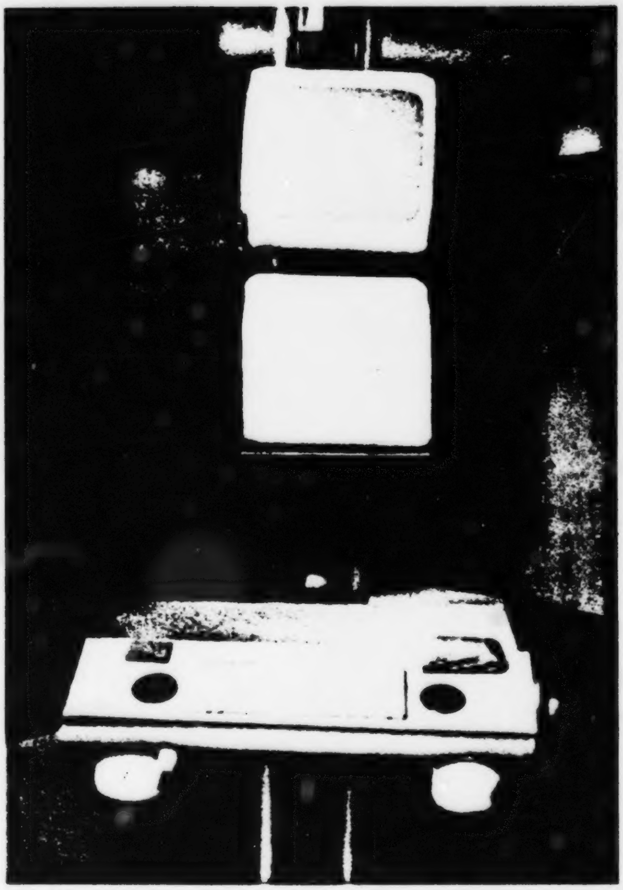


Fig. 5

All components come off vertical column like branches

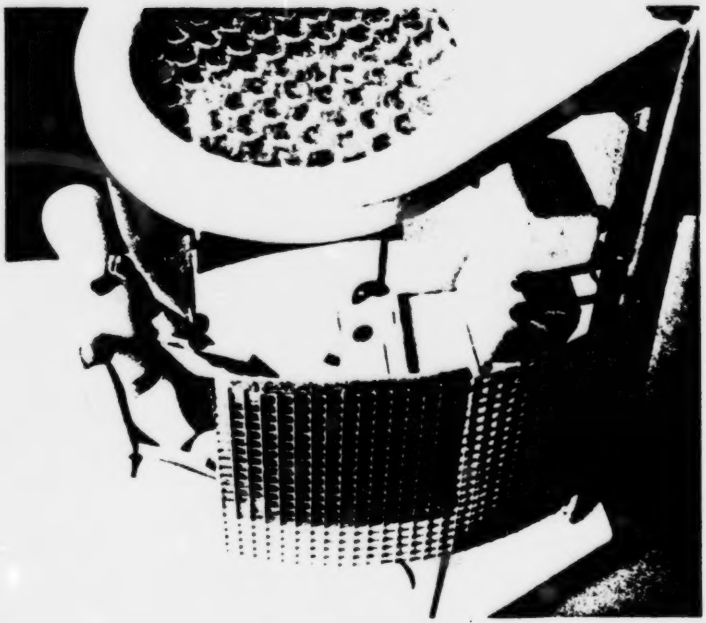


Fig. 6
Diffuser and curved panels

Fig. 7
CAL-COON, enclosed, fully controlled working environment with built-in seat

Fig. 8
Built-in components with remote keyboard

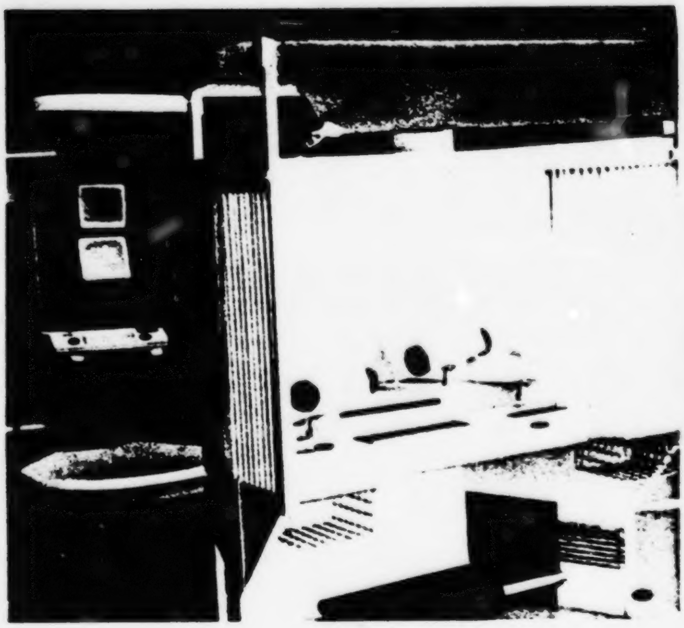


Fig. 9
CAL-STATION, adjustable and reclinable worksurface

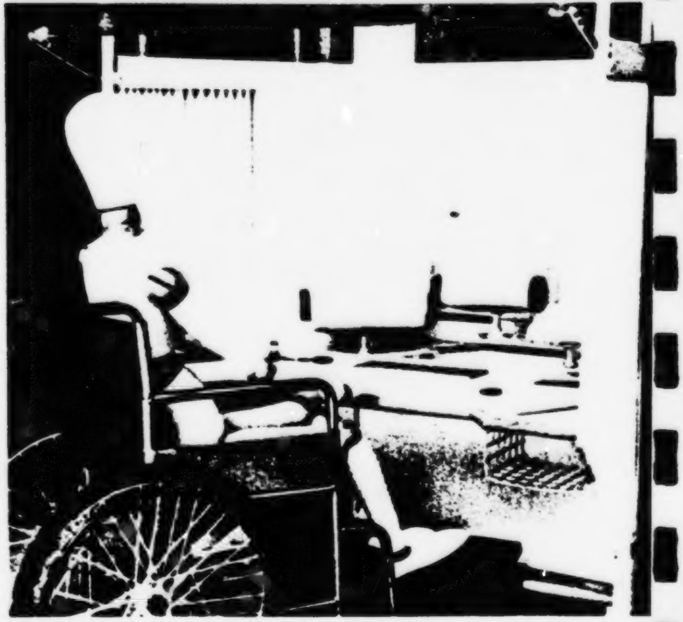


Fig. 10
Access for wheelchair user

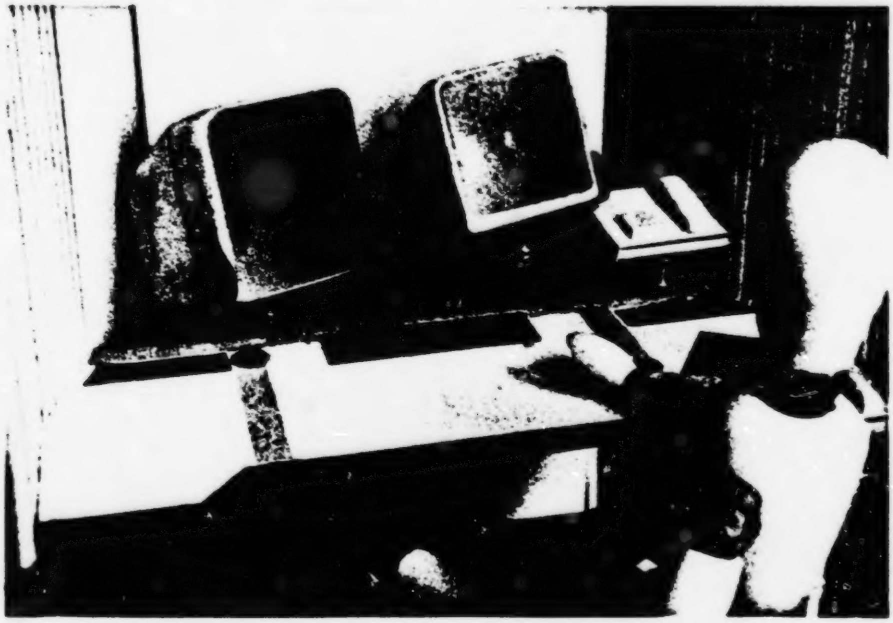


Fig. 11
Left and right sliding trackball, hand controls and two monitors

Fig. 12
Designer, verifying user-component interface

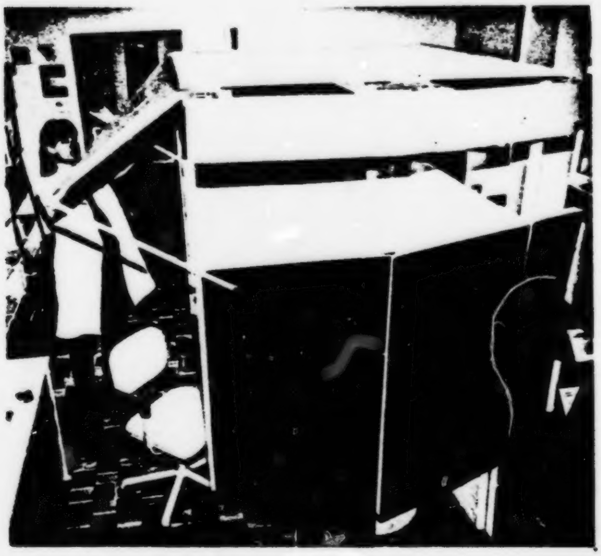


Fig. 13
Preliminary full scale mock-up to assess size and volume

Fig. 14

Demonstration of reference material in Dorval's centre

Fig. 15

Technician's manual

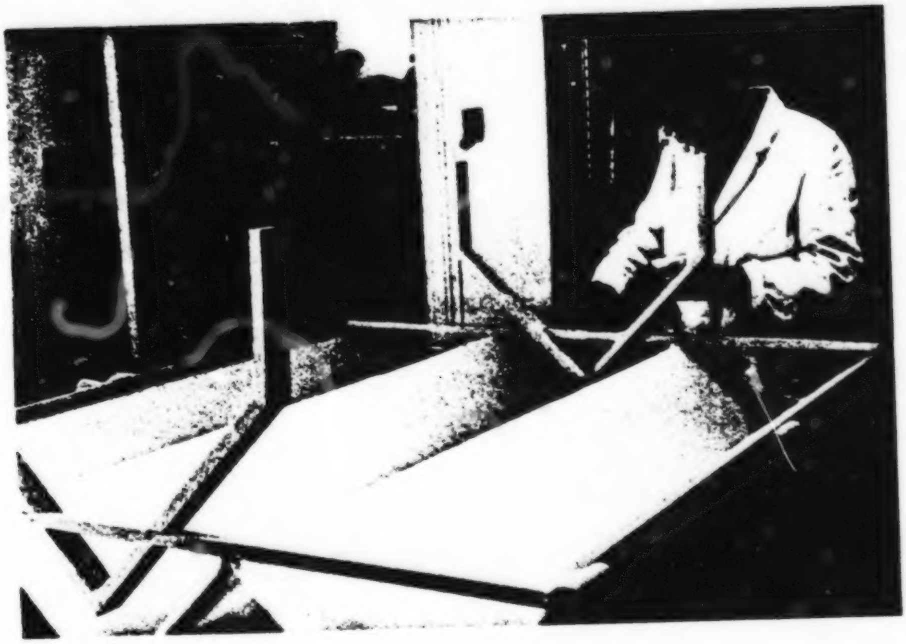


Fig. 16
Building of mock-up components

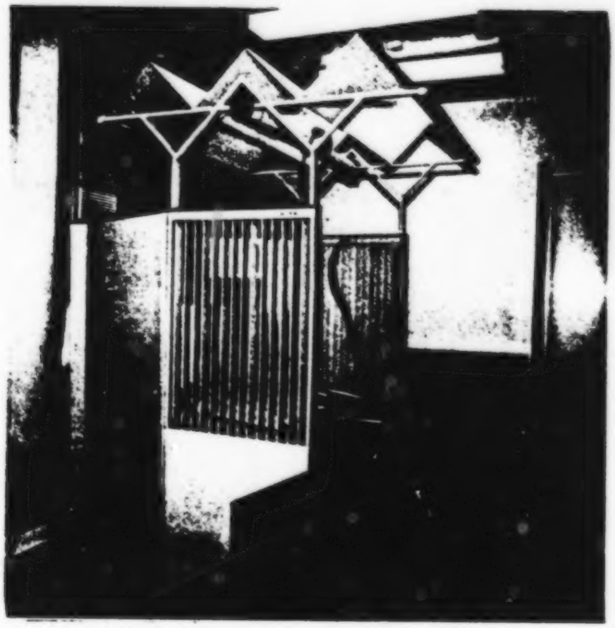


Fig. 17

FINAL DESIGN OF CAL-STATION

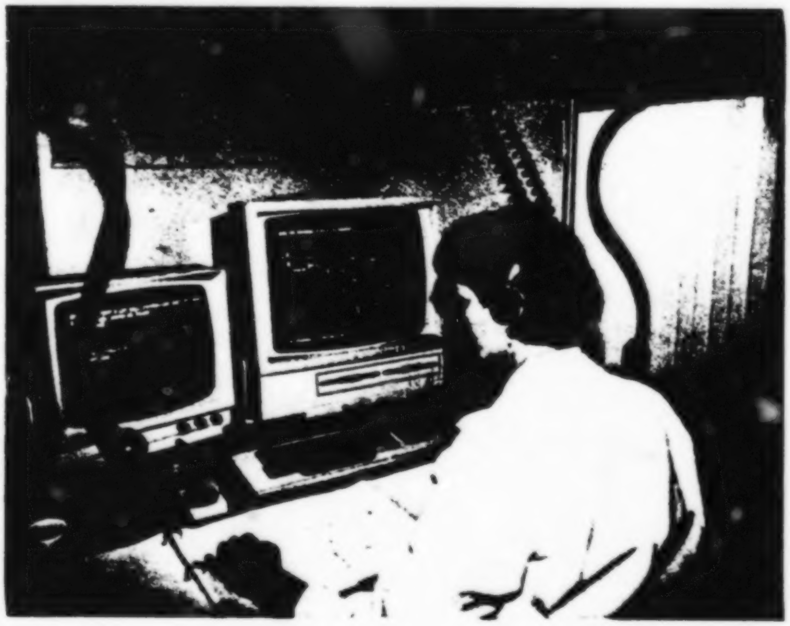


Fig. 18

Simulated use of two monitors, earphones and personal manual

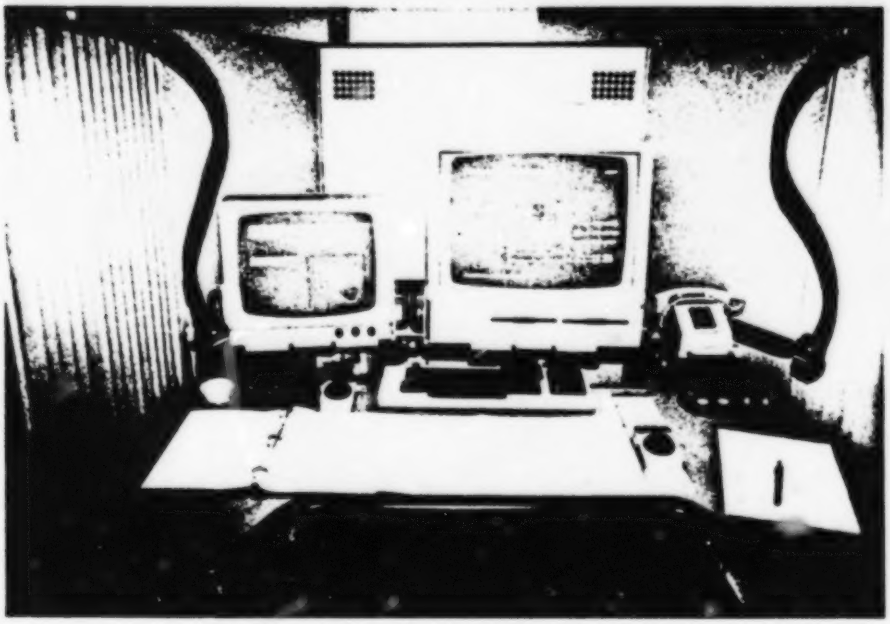


Fig. 19
Full workspace lay-out with adjustable louvers left and right

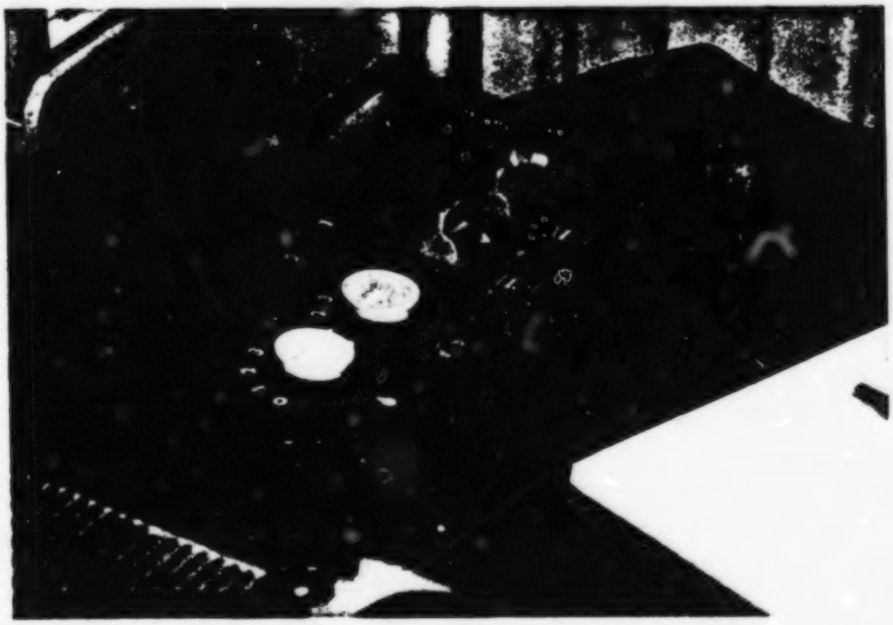


Fig. 20
Control panel for light, sound, table hight and angle adjustments

Fig. 21
Adjusting telephone location

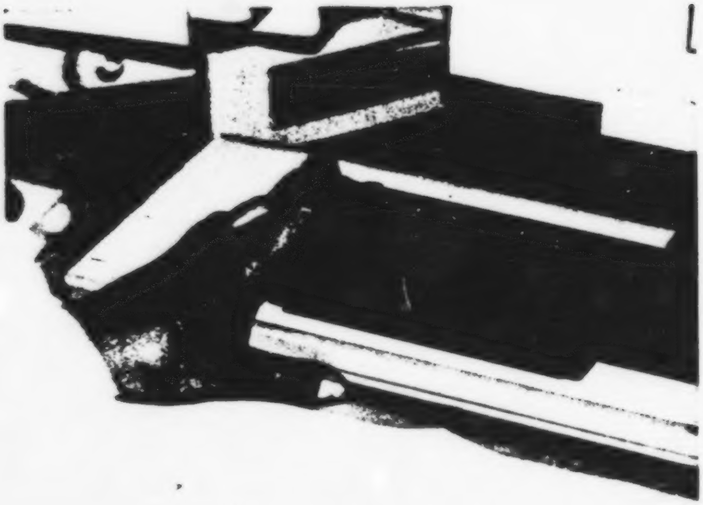


Fig. 22
Use and position of keyboard

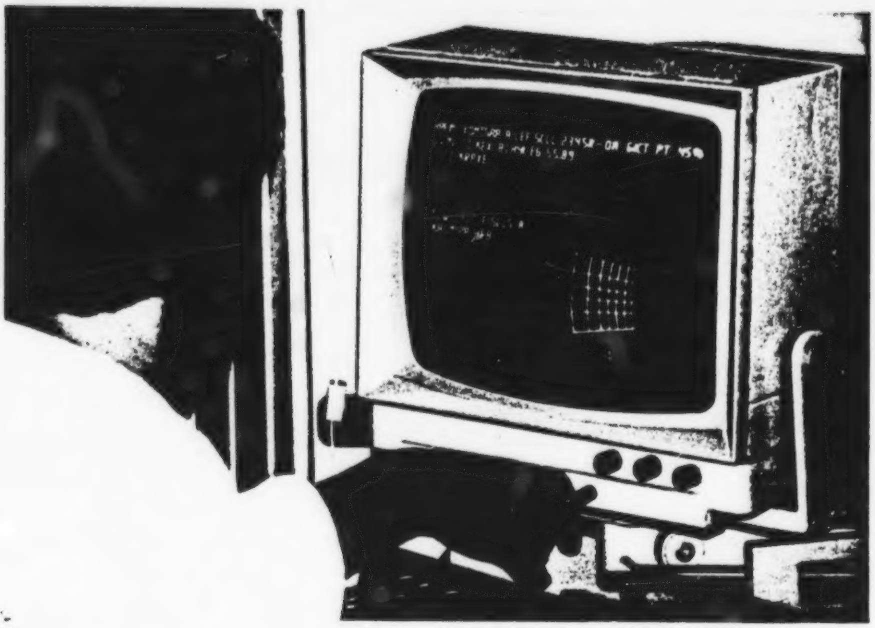


Fig. 23
Adjusting monitor for distance

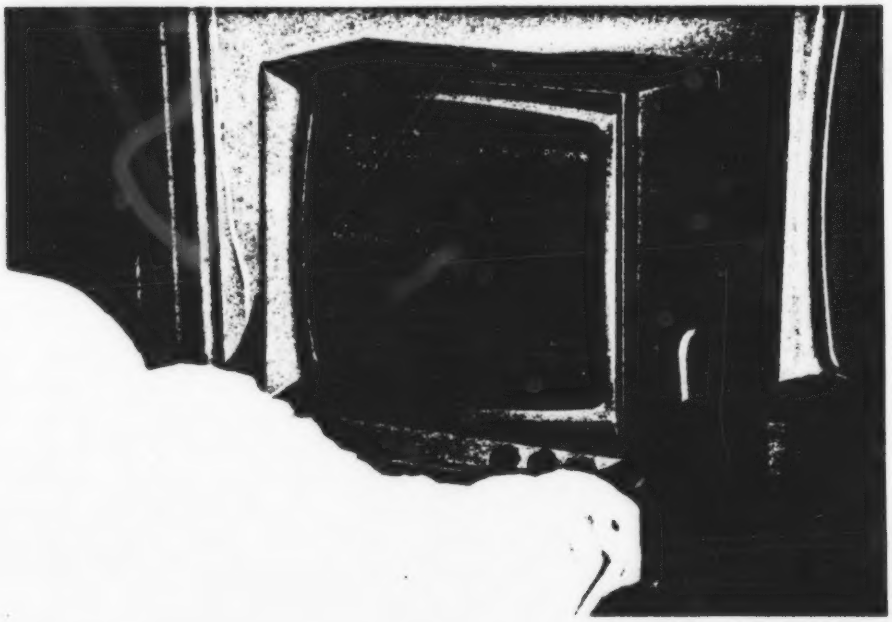


Fig. 24
Monitor adjustment for correct angle

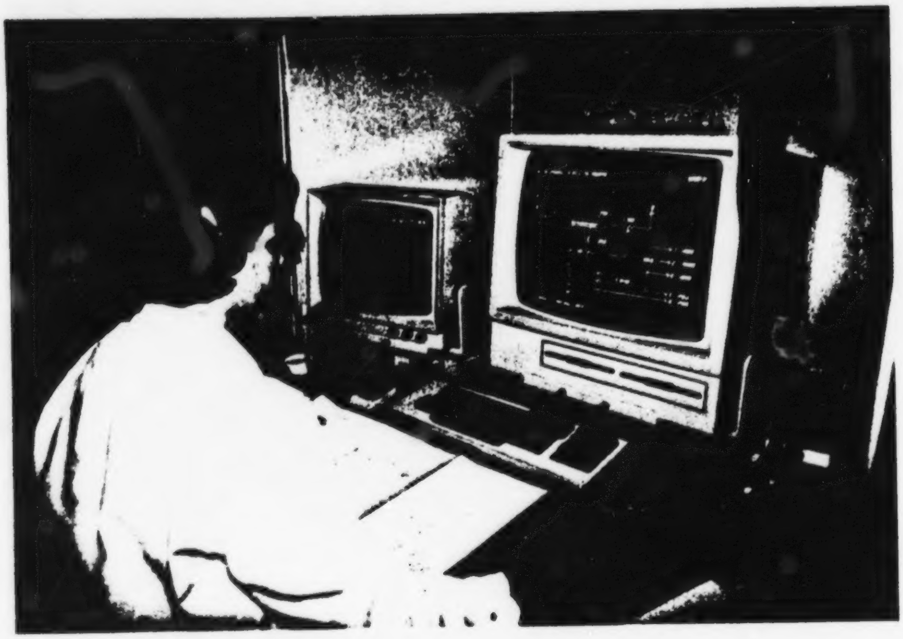


Fig. 25

Position of sliding trackball controls

Fig. 26

Left hand side

Fig. 27

Right hand side

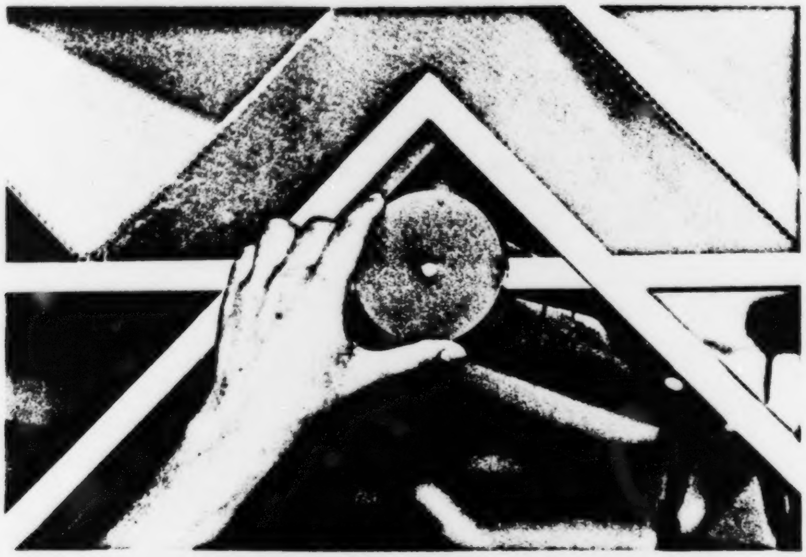


Fig. 28

Ambient light adjustment

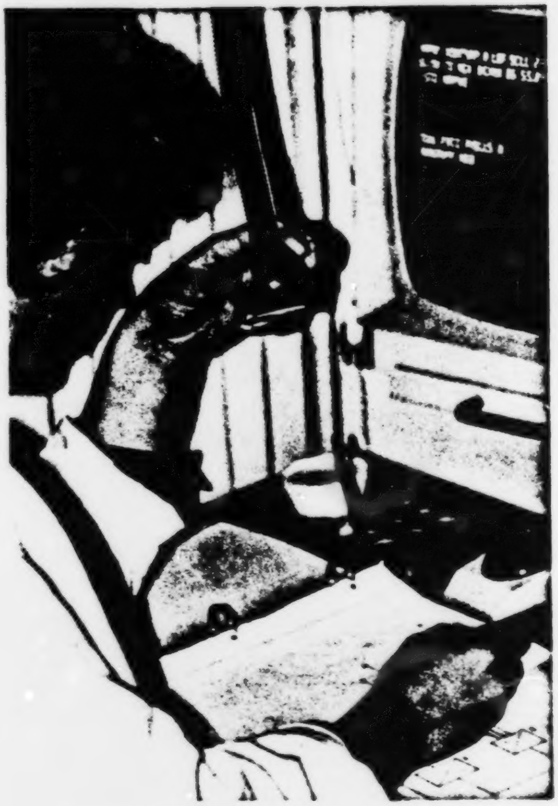


Fig. 29

Task light

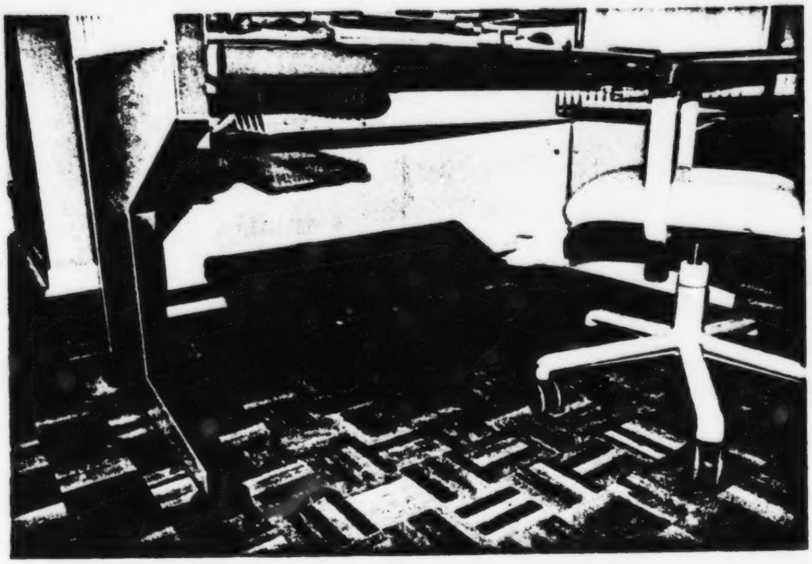


Fig. 30
Adjustable footrest

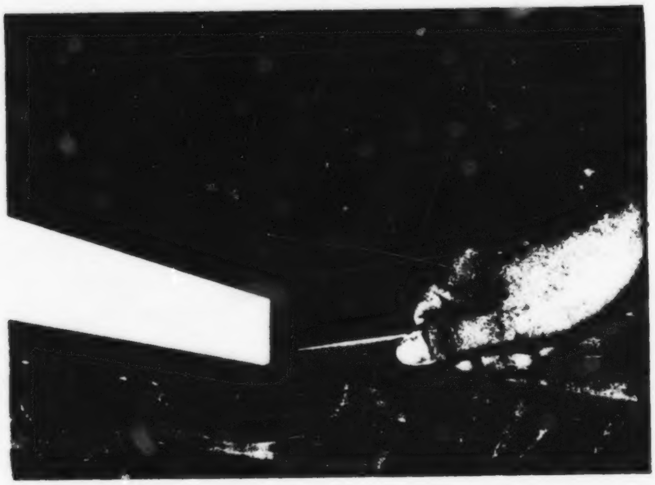


Fig. 31
Adjusting floor leveling device

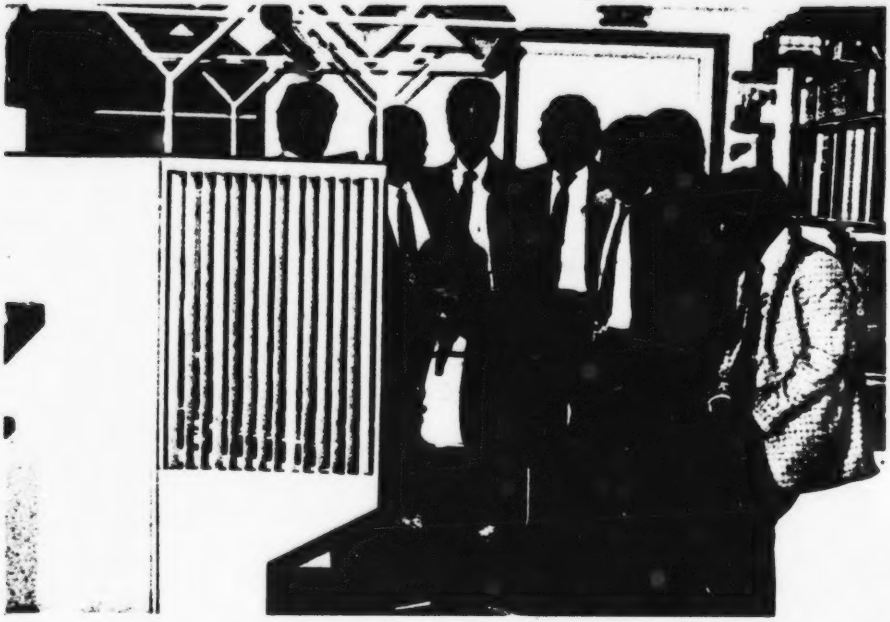


Fig. 32
Presentation and evaluation of final design